Subacromial Impingement Syndrome:

A Study Using

Clinical, Functional and Electromyography Assessments

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor of Philosophy (PhD)

By

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Abstract

Background

Subacromial impingement syndrome (SIS) is the most common diagnosis made in patients with chronic shoulder pain, accounting for 44-65% of all complaints of shoulder pain. SIS is a clinical diagnosis describing a multifactorial pathology applied to a condition whose main clinical symptoms are anterior or anterior-lateral superior shoulder pain, associated with restricted elevation of the arm or when attempting overhead activities, but without specific clinical tests. This study uses a battery of clinical, functional and EMG investigations in well-defined patient and control groups, in order to identify and measure aberrations in shoulder movements common to patients with SIS, to establish the consequences for shoulder girdle control and ultimately to suggest which therapeutic strategies might be most successful.

Participants

Thirty four healthy controls including males and females, different ethnic groups and handedness completed all the tests and tasks. EMG studies were performed on either dominant or non-dominant sides, non-EMG evaluations were undertaken bilaterally. Thirty nine patients with a clinical diagnosis of SIS were evaluated, categorised and tested as for the healthy volunteers whereby all non-emg studies were performed bilaterally and the EMG tasks performed by the affected shoulder.

Materials and Methods

Fourteen standard clinical tests were used to define the patient's shoulder problems and establish the status of the healthy shoulders. Muscle strength range of motion, posture and functional tests were applied and answers to validated clinical questionnaires compiled. The electromyographic activity of 15 shoulder muscle girdles was investigated during cyclic upper extremity functional tasks using a wireless Noraxon system with a combination of surface and fine-wire electrodes. Functional tasks included the painful movement range typical of SIS. A shoulder-specific myometer and EMG recording were used to measure the shoulder strength during four distinct shoulder movements and fatigability of muscles during 25% maximum voluntary contraction. Data analysis packages and integration systems

were used to assimilate changes in the activities of individual muscles into common patterns of aberrant control of the shoulder girdle.

Results

No differences in shoulder functional capacity were detected between different ethnic groups or between dominant and non-dominant shoulders. However, males were significantly stronger than females. The differences between patients with SIS and controls resulted in aberrant positioning and control of the scapular which then had knock on effects with the associated humeral head centring and deltoid activation. The muscles most susceptible to fatigue differed depending on the activity being undertaken. The serratus anterior was highly susceptible to fatigue during flexion and abduction while the infraspinatus fatigues during external rotation and the supraspinatus during internal rotation

Discussion and Conclusion

Normal neuromuscular control of scapular positioning and motion during arm elevation and lowering provides the stable base for the head of humerus to rotate securely by efficient co-activation of muscles and in harmony with scapular motion. Pain, weakness, restricted joint motion and faulty upper body posture are frequent manifestations in patients with subacromial impingement that have mutual effect on the scapular coordination. Aberrations in scapular positioning and control underpin many of the problems associated with SIS. Physiotherapy aimed at correcting posture and the use of muscle-specific strengthening exercises will help to readjust the scapula-humeral rhythm and improve patient shoulder function.

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Abbreviations

Amplitude	AMP
Anterior deltoid	AD
Biceps brachii	BB
Bilateral impingement	BIMP
Constant-Murley score	CMS
Central nervous system	CNS
Disability of arm, shoulder and hand	DASH
Disability of arm, shoulder and hand –option 1	DASH-Op1
Disability of arm, shoulder and hand –option 2	DASH-Op2
Electrocardiogram	ECG
Electromyography	EMG
Eye-Down Task	EDT
Fast Fourier Transformation	FFT
Female Control	FC
Forward head posture	FHP
Forward shoulder posture	FSP
Functional Impairment Test-Hand, and Neck/Shoulder/Arm	FIT-HaNSA
General Health Survey SF-12	GHSF-12
Glenohumeral Joint	GHJ
Hospital Anxiety and Depression Scale	HADS
Humeral head centring	HHC
Hospital Anxiety and Depression Scale	HADS
Infraspinatus	ISP
Interference Pattern	IP
Internal-External Rotation Task	IERT
International society of electrophysiology and kinesiology	ISEK
Lateral scapular slide test	LSST
Latissimus dorsi	LD
Levator scapulae	LS
Lower trapezius	LT
Male control	MC
Maximum voluntary contraction	MVC
McGill pain questionnaire	MPQ
Mean frequency	MnF
Median frequency	MdF
Middle deltoid	MD
Middle trapezius	MT
Normalized scapular protraction	NSP
Overhead Task	OHT
Oxford Shoulder Score	OSS
Patient Group	PG
Pectoralis Major	PM
Posterior deltoid	PD
Present Pain Intensity	PPI
Range of Motion	ROM
Rhomboid major	RM
Root mean squarer	RMS

Rotator cuff	RC
Scapular setting	SS
Scapular positioning muscle group	SPMG
Scapulohumeral rhythm	SHR
Scapulothoracic Articulation	STA
Serratus anterior	SA
Scapular index	SI
Subacromial Impingement Syndrome	SIS
Subscapularis	SUBS
Supraspinatus	SSP
Surface EMG for the Non-Invasive Assessment of Muscles	SENIAM
Teres major	TM
Thoracic kyphosis index	TKI
Unilateral Impingement	UIMP
Unilateral Impingement with associated pathology	UIMPlus
Upper Limb Functional Index	ULFI
Upper trapezius	UT
Waist-Up Task	WUT

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1 CHAPTER ONE: INTRODUCTION

1.1 Subacromial Impingement Syndrome

It is estimated that possibly as many as 1 in 3 people will develop shoulder pain during their life. In many this will become chronic and be associated with disability[33]. The prevalence of self-reported shoulder pain was estimated as 16%[34] in the UK, rising to 26%[35] in the elderly; and in the Netherlands was reported as 21%[36]. Subacromial impingement syndrome (SIS) is still the most common diagnosis made in patients with chronic shoulder pain, accounting for 44-65% of all complaints of shoulder pain reported in a visit to a physician[37,38]. Kaikkonen et al. (2009)[39] discussed the prevalence of SIS in different patient groups including heavy manual workers and athletes. Although SIS is a diagnosis that has become increasingly common, it remains an ill-defined entity[40]. The non-specific nature of the symptoms and signs may mean that the 'impingement' is secondary to pathology such as instability or associated with a rotator cuff tear[41]. Arthroscopic subacromial decompression is the procedure of choice for patients with impingement syndrome refractory to conservative treatment[42].

SIS describes a condition whose main clinical symptoms are anterior or anterior-lateral superior shoulder pain, often associated with restricted movement of the shoulder girdle. The pain is experienced during elevation of the arm or attempting overhead activities occurring in many normal activities at home, during work and in sport. SIS is a clinical diagnosis, though the accuracy of the diagnosis is difficult because of multifactorial pathology, shoulder structural complexity and lack of specific clinical tests. A few studies have reported a relatively higher sensitivity, specificity and reliability with the use of combinations of tests[43-45]. 'Typical' changes on radiographs, such as spurs on the acromion and the eyebrow sign, may be absent. The symptoms and signs of SIS are a result of pathology within structures located within or adjacent to the subacromial space. SIS has been described as mechanical compression of the rotator cuff and other subacromial tissues between the proximal end of the humerus and coracoacromial arch[46], but the aetiopathology is still unclear. Neer (1972)[46] argued that the anterior one-third of the acromion, the coracoacromial ligament and, at times, the acromioclavicular joint impinged upon the subacromial components mainly when the arm was in a position of forward elevation.

Although the principles of arthroscopic subacromial decompression (i.e. a combination of removing the anterolateral part of the acromion, a release of the coracoacromial ligament and a subacromial bursectomy), described by Neer[46] 40 years ago are still in use with good outcomes, the definitive pathology of SIS remains unclear. There is a growing body of evidence that altered muscle activation patterns and muscle coordination imbalance are associated with the aetiology[4,47]. Changes in range of motion (ROM)[19], muscle strength[47-50] and muscle balance[51-53] deficits and upper body posture[54,55] have been found in patients with SIS and changes may correlate with functional capacity. Physiotherapy programmes that address posture, abnormalities of shoulder movement and muscle activation have been shown to be associated with 67% recovery rate for patients who have impingement syndrome[56,57].

In order to investigate physiological factors that may contribute to SIS, patients need to be identified using accepted clinical tools that enable selection of a coherent patient group with well-defined symptoms and signs. Potential coexisting pathology such as rotator cuff tears and biceps tendon degeneration needs to be excluded wherever possible. In addition, physiological factors must be investigated using reliable and validated tools. This study uses the functional impairment test for the upper extremity and neck described by MacDermid et al. (2007)[58], an electronic myometer and electromyography (EMG) measurements. The Functional Impairment Test-Hand, and Neck/Shoulder/Arm (FIT-HaNSA) resembles daily living activities of the shoulder and upper limb at the waist level, up to the eye level and overhead reaching. The Mecmesin myometer is used to measure isometric maximum voluntary contraction in four standardized movements (flexion, abduction, internal and external rotation). EMG is used to record myoelectric signals from shoulder muscles and reflects the muscle activation pattern, maximal activation level and muscle fatigue. When EMG is precisely synchronized with video images of shoulder motion, inferences can be made regarding the roles of muscles for producing the observed motions. Furthermore, simple direct in vivo measurements and measurements on lateral photographs for upper body posture are used to investigate correlations between variations in posture and muscle activation.

1.2 Hypotheses

- In patients with primary subacromial impingement syndrome scapular positioning is abnormal at initiation of forward elevation or abduction from the adducted position.
- Changes in muscle activation patterns, particularly of periscapular muscles cause an abnormal pattern of scapular movement during upper limb movements in patients with SIS.
- Differences in muscle fatigue between patients with SIS and normal individuals will reflect adaptations in muscle activation and shoulder girdle movement.

1.3 Aims of the Study

- To determine whether gender, ethnic group or hand preference influence normal shoulder function.
- To identify and categorize patients with SIS using a series of clinical assessments and functional tests.
- To measure differences in the functional capacity of the shoulder girdle of patients with SIS relative to that of healthy controls.
- To identify factors that may influence the functional capacity of the shoulder such as upper body posture, muscle strength or muscle fatigue.
- To analyse differences in individual muscle activity patterns between patients with SIS from that of healthy controls.
- To explain the effect of any differential muscle activity identified in patients with SIS on shoulder girdle control during upper limb movements.
- To detect any common aberrations in shoulder girdle functioning which might underpin SIS.

1.4 Objectives:

- To recruit both patients diagnosed with SIS prior to treatment and a matched group of volunteers with normal shoulder function
- To use validated questionnaires to record pain and functional capacity in normal controls and patients with SIS.
- To examine shoulder function using accepted physical tests and to define clinically the shoulder pathology.
- To assess the correlation of the following with the severity of subacromial impingement:
    - Pain and functional disability
    - Upper body postural changes
    - Shoulder muscle strength.
- To assess the activity patterns of 15 shoulder muscles using EMG recordings performed during tasks that simulate activities of daily living.
- To determine shoulder functional performance during dynamic arm motion and overhead work.
- To analyse the individual muscle EMG patterns for inter-muscle coordination.
- To determine differences in muscle activation patterns between patients and volunteers.
- To assess the EMG records of 15 shoulder muscles for maximal activation level and sustained submaximal muscle fatigue in patients and healthy controls.

By integrating detailed data from carefully selected groups of patients and controls, using standardised protocols within the capacity of patients to complete, the study will shed light on differences in shoulder girdle functioning in patients with SIS. This may enable improved therapeutic strategies to be developed.

2 CHAPTER TWO: REVIEW OF LITERATURE

2.1 Subacromial Impingement Syndrome

Subacromial Impingement Syndrome (SIS) is believed to be the most common cause of shoulder pain, accounting for 44% to 65% of all complaints of shoulder pain requiring a consultation with a doctor[37,59]. This shoulder disorder traditionally refers to the compression of the subacromial space interposing soft tissues between the acromion and coracoacromial arc superiorly and the head of the humerus inferiorly, causing potential damage to the rotator cuff tendon, long head of the biceps tendon, subacromial bursa, and the shoulder capsule[60,61,46]. It is a non-specific, ill-defined entity or syndrome associated with shoulder pain particularly during arm elevation or overhead activities. SIS may result in chronic pain with functional disability[62,32,19]. A variety of conditions acting independently or in combination may lead to a potential or a true narrowing of the subacromial space. It is believed that a variety of intrinsic pathologic factors, for example, inflammation and degeneration of the rotator cuff due to tension overload, or muscle imbalance may lead to 'intrinsic impingement'[63,64], whereas 'extrinsic impingement' is thought to be due to acromial and coracoacromial arch pathology[46,65,66,48] and degeneration and inflammation of tendons or bursa[31,67]. More recently an increasing body of research has been investigating altered scapulothoracic and glenohumeral kinematics[68,10,69-71], muscle activation imbalance, faulty posture[72,73,47] and posterior capsular tightness[68,74,75] as possible aetiological factors in SIS. These potential mechanisms can occur individually or in combination, an issue that hinders the diagnosis and treatment of the condition.

2.1.1 Historical Background

Meyer[76], in (1931), described the attrition changes on the inner side of the subdeltoid bursa in the region of the greater tuberosity. Subsequently the apparent abnormal contact between the coracoacromial arch and the underlying soft tissues particularly the rotator cuff tendons was investigated[77-80,46,81]. Codman (1943)[77] defined the degenerative changes and their location in the rotator cuff tendons. Armstrong (1949)[78] introduced the term 'supraspinatus syndrome' and its treatment with 'total acromionectomy' while McLaughlin and Asherman (1951)[82] tried to conserve the acromion by 'lateral acromionectomy'. The disappointing results of total and lateral acromionectomy together with the investigations conducted by Neer (1972)[46], led to the introduction of the concept of 'SIS' as a degenerative change starting at the anterior one-third of the acromion, the coracoacromial ligament and the acromioclavicular joint. Based on his hypothesis, Neer described anterior acromioplasty. The standard surgical procedure[83-87] is now an arthroscopic version of the acromioplasty described by Neer. In addition to the removal of anterior third of the acromion, debridement may be extended to involve the inferior portion of the coracoacromial ligament and acromioclavicular joint[46].

Clinical electromyography (EMG) was first introduced by Adrian and Bronk (1929)[88]. Inman (1944)[4] described a coupling phenomenon between the scapular motion and arm elevation known as 'scapulohumeral rhythm' which is considered the base-line for the normal behaviour of the shoulder complex. Basmajian (1963)[89], undertook intensive EMG work on muscle function and established the principles and practical guides for EMG electrode placement by clinicians. Based on EMG studies, many authors have found alterations in muscle activation patterns between patients with SIS and healthy subjects, or between affected and unaffected shoulders[47,19]. The existing inconsistency in the published data, as observed in the activation magnitude and timing of the parts of trapezius and SA muscles, can be attributed to different protocols of assessment and natural myoelectric differences between people[48]. EMG studies have greatly increased the understanding of the relative muscular contributions to shoulder kinematics. Computerized 3D analysis, which is established as a non-invasive method for recording dynamic shoulder motion, combined with EMG profiles of shoulder muscles, provides the essence of the shoulder kinematics[19].

2.2 Functional Anatomy of the Shoulder

In activities of daily living, the performance of the upper extremity depends on the functional integrity of each joint of the upper limb and trunk. Effective hand positioning and performance is a consequence of normal shoulder and elbow movement. Contributing to this is the fact that good shoulder function is a combination of painlessness, mobility and stability[90]. The shoulder complex consists of the shoulder girdle (clavicle and scapula) and the humerus. There are three synovial joints; sternoclavicular , acromioclavicular and glenohumeral joints; and a single sliding articulation of the scapula on the thorax named the scapulothoracic articulation (STA). The remarkable mobility of the shoulder complex is determined by three factors: its single connection to the axial skeleton through the sternoclavicular joint, the size differential between the humeral head and glenoid cup at the glenohumeral joint (GHJ) with a ratio of 3:1respectively, and the widely sliding STA. This range of motion at the shoulder complex requires efficient static and dynamic stability and coordination.

2.2.1 Sternoclavicular Joint

The sternoclavicular joint is a saddle-type synovial joint formed by the convex medial end of the clavicle and the concave surface of the clavicular facet of the sternum. An intra-articular disc allows compensation for mismatching of articular facets and acts as a shock absorber. It is approximately 3-10 mm thick with a thicker anterior portion. This is important for the mobility of the joint, transmission of forces and function of the whole upper extremity[91]. The joint is strongly reinforced by the anterior and posterior SC ligaments and capsule as well as the interclavicular and costoclavicular ligaments. The SC joint allows clavicular elevation and depression between 45° and -10°, retraction and protraction of about 15° and 50° of posterior rotation along the long axis of the clavicle[92].

2.2.2 Acromioclavicular Joint

The acromioclavicular joint is a plane-shaped synovial joint formed by the lateral end of the clavicle and medial side of the acromion. An intra-articular disc is sometimes identified especially in younger persons, which increases the congruity of the articular surfaces and provides protection from transmitted forces. The joint is reinforced by the joint capsule, its superior thickening called the superior acromioclavicular ligament, and the costoclavicular ligaments. Because of the shape of articular surfaces, capsular and ligamentous envelope, the movements of the clavicle are transmitted to the scapula across the acromioclavicular joint. Any restriction to the synchronized movements between the clavicle and scapula, as in painful acromioclavicular joint conditions or mal-alignment of the clavicle, will affect the function of the STA[93].

2.2.3 Scapulothoracic Articulation

The scapulothoracic articulation (STA) allows movement of the scapula on the thoracic ribs. The shoulder girdle (scapula and clavicle) components have a synchronized motion which results from coordinated motion of the sternoclavicular joint, acromioclavicular joint and STA[92]. Scapular movement has been described in multiple planes, including upward elevation and downward depression, upward and downward rotation, anterior and posterior movement along the thoracic cage termed protraction and retraction as well as small adjustments along the acromioclavicular joint plane. The major muscles responsible for scapular movements include the trapezius, levator scapulae, serratus anterior, and rhomboids.

2.2.4 Glenohumeral Joint

The fundamental central component of the shoulder complex is the GHJ. It has a ball-and socket configuration with a surface area ratio of the humeral head to glenoid fossa of about 3:1 with an appearance similar to a golf ball on a tee[94]. Overall, there is minimal bony covering and limited contact area extended by the glenoid labrum that allow extensive translational and rotational ability in all three planes via combinations of multiple muscles. Stability is created through both static (passive) and dynamic (active) mechanisms which allows a wide range of GHJ mobility during daily activities[61].

2.2.5 Subacromial Space

Pfuhl (1934)[95], was the first to define the subacromial region as 'subacromial accessory joint of bone-muscle-bone gliding interface' and insisted that the subacromial and subdeltoid bursa is single entity. The acromion and the coracoacromial ligament form the roof while the head of the humerus forms the floor of the potential subacromial space. The height of the subacromial space varies from 1.0 to 1.5 cm as seen on radiographs of healthy subjects[96], while in patients with SIS the height is reduced by about 3 mm or more as compared to unaffected shoulder at 90° of isometric GHJ abduction[97]. A decrease in the width of the acromio–humeral interval occurs during GHJ abduction[60,98,97] and an increase in the contact between the inferior acromion and underlying subacromial tissues occurs during GHJ abduction and flexion[72,96]. Contact pressure and force in the subacromial space has also been demonstrated to increase during GHJ abduction, with the highest subacromial force and contact pressure observed in the mid-range of motion[99-101].

2.3 Stability of the Shoulder Complex

Shoulder muscles have been classically divided into four groups based on muscle attachments. They include: 1) axioscapular, 2) axiohumeral, 3) scapulohumeral, and 4) extrinsic muscles[4] [Table 2 – 1].

Table 2 - 1: Classification of shoulder muscles according to their attachments (information obtained from[4])

Muscle groups	Shoulder muscles
Axioscapular muscles	Levator scapulae (LS), trapezius includes upper (UT), middle (MT) and lower (LT) portions, serratus anterior (SA), rhomboid major/minor (RM/Rm), pectoralis minor (Pm).
Axiohumeral muscles	Pectoralis major (PM) and latissimus dorsi (LD)
Scapulohumeral muscles	Rotator cuff (RC): supraspinatus (SSP), Infraspinatus (ISP), subscapularis (SUBS) and teres minor (Tm); in addition to teres major (TM) and deltoid includes anterior (AD), middle (MD) and posterior (PD) portions
Extrinsic muscles	Biceps brachii (BB) and triceps

2.3.1 Stability of the Scapulothoracic Articulation and the Primary Role of the Scapula

The scapula acts as a stable platform from which GHJ mobility occurs[102]. The primary role of the scapula is to provide the proper alignment of the glenoid to the humeral head not only for optimal bony stability but also to facilitate muscular constraint by maintaining proper length-tension relationships for efficient contraction of the RC and deltoid muscles. In addition to the ligaments at the sternoclavicular joint, acromioclavicular joint and the 'suction mechanism' induced by the SA and SUBS muscles, the main dynamic stabilizers of STA are the levator scapulae, trapezius, serratus anterior and the rhomboids. These muscles, together with the stabilizers of the GHJ, function through synergistic co-contraction to maintain the balance of movement between the joints of the shoulder girdle, thus maintaining scapulohumeral rhythm (SHR) as described by Inman (1944)[4]. As the scapular stabilizers and the placement of the scapula depends on their integrity with the axial skeleton and thorax, any alteration in the cervical and thoracic spine alignment and shape of thorax may lead to dysfunctional instability in the STA and GHJ[103,104].

2.3.2 Stability of the Glenohumeral Joint

The stability is created through both static (passive) mechanisms and dynamic (active) mechanisms at rest, mid-range and extremes of motion.

Static stability: Static restraints include concavity of the glenoid fossa, glenoid fossa alignment and inclination, the glenoid labrum (which enhances glenoid fossa depth by about 50%), the joint capsule and glenohumeral ligaments, and a vacuum effect from a negative intra-articular pressure. It is estimated that the labral structures represent 10 to 20% of stabilization forces[105]. Rotator cuff and deltoid muscle mass also help compress the joint at rest. All of these static restraints are important at rest, except for the glenohumeral ligaments, which seem to be important at extremes of motion. During upper extremity movement, the effects of static restraints are minimized as the joint approaches the mid-range of movement and dynamic or active stabilizers become the dominant forces to achieve stability.

Dynamic stability: The aim of dynamic mechanisms is to ensure centring of GHJ and minimize humeral head translation particularly at the mid-range of motion when the static elements are not efficient to provide GHJ stability. Lippitt (1993)[106] reported the 'concavity compression' mechanism when the head of the humerus is actively compressed against the glenoid cavity by axiohumeral muscles crossing the GHJ. This mechanism is determined by the compressive forces of crossing muscles and depth of the glenoid fossa[107,108]. The scapulohumeral muscle group, which includes the rotator cuff, deltoid and long head of biceps, is responsible for centring the humeral head within the glenoid fossa. Moreover, during upper limb motion and loading, the steady setting of the scapula leads to increased tension of the muscles of the rotator cuff, enhance their ability to resist a change in length and maintain efficient stabilizing activity with the arm between 70° and 100° of abduction[109,110].

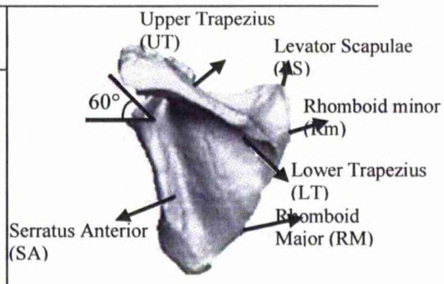
2.3.3 The Force Couples Motion Control

A couple is a term used to describe rotatory motion brought about by forces that are generally equal in magnitude and act in opposite directions at some distance from each other to provide stability. Furthermore, the force couple concept may extend to include opposing co-contracted muscles to provide coordinated rotations of the scapula and humerus[4,111,112]. Accordingly, the muscle sling groups around the scapula are examples of the coupling mechanism at STA [Table 2 – 2].

Table 2 - 2: Scapular muscle slings (adapted from[4])

SA: serratus anterior, RM: rhomboids major, Rm: rhomboids minor, LS: levator scapulae, UT: upper trapezius, MT: middle trapezius, LT: lower trapezius, Pm: Pectoralis minor

Muscle sling	Balanced action
SA – RM sling	Medial – lateral rotation
LS – LT sling	Elevation – depression
SA – UT sling	Upward – downward rotation
UT, MT, LT – Pm* sling	Retraction – protraction



The components within a muscular sling either co-contract and facilitate controlled movements of the scapula in the STA or apply equal forces in opposite directions and fix the scapula in specific position[91]. Individual or combined slings act to move and stabilize the scapula. For example, the upper trapezius and lower digitations of serratus anterior form an upper component with the lower trapezius, a lower component of a force couple producing upward rotation of the scapula. A second example, rhomboids, levator scapulae and upper digitations of serratus anterior form an upper component while pectoralis major together with latissimus dorsi form a lower component of a force couple producing downward rotation of the scapula. Finally, the deltoid forms an upper and the rotator cuff a lower component of a force couple that centres the humeral head within the glenoid fossa as the distal humerus is elevated[111]. Axio-scapular muscles are also recruited to control the scapula such that the humeral head has a stable glenoid platform on which to rotate.

Movement of the scapula on the thorax is essential for normal function of the upper extremity[113]. The proper dynamic positioning of the scapula is a prerequisite for accurate centring of the head of the humerus in the glenoid fossa and sufficient clearance of the subacromial space, which allows effective arm elevation and overhead reaching[110,2].

2.4 Scapulohumeral Rhythm (also Called: Humeroscapular Rhythm)

Codman (1934)[77] used the term scapulohumeral rhythm (SHR) to indicate coordinated proportional rotations at the GHJ and STA which are determining factors of humeral abduction and flexion. On clinical basis, this dynamic relation of SHR is valuable as its disturbance may indicate a pathological shoulder. Inman et al. (1944)[4] reported the ratio of GHJ to STA rotations as 2:1 during the full range of arm elevation. In fact, there is more movement of the GHJ than STA at a ratio of 4:1 during the first 30° of abduction and 60° degrees of flexion; then it continues at a ratio of 5:4[18,2]. McClure et al. (2001)[5] directly measured scapular 3-D motion during active scapular plane elevation and lowering in 8 healthy men and women. The overall ratio of GHJ to STA motion was 1.7:1. The scapula upwardly rotated 50°, tilted posteriorly around a medial-lateral axis 30°, and externally rotated around a vertical axis 24°. Lowering of the arm resulted in a reversal of these motions with a slightly different pattern[5]. Further, considerable variations in the coordinated motion between the GHJ and STA during overhead reaching has been reported in various studies[114]. Nonetheless, when averaged over the total arc of elevation, the relative contributions of GHJ and scapulothoracic joint motion were essentially and consistently 2:1 as reported in the literature[4].

2.5 Arm Elevation and Overhead Reaching

A kinematic model that emphasises the coordinated movements of the clavicle, scapula and humerus was reviewed by Hurov (2009)[92], and based on the work of Dvir and Berme (1978)[2]. Few 2-D and 3-D direct measurements and real-time tracking systems shared shoulder kinematic mechanisms in voluntary arm elevation in the scapular plane and overhead reaching[5,9,115,116].

The chain of events during arm elevation in flexion and abduction are divided into 4 phases[117] [Figure 2 - 1]. Phases 1&2, the arm is elevated to 60° in flexion or 30° in abduction and include: (a) Elevation of the lateral end of the clavicle by 12-15°, (b) Scapular upward rotation by 5-15° on an anteroposterior axis, known as 'scapular setting (SS)'[4], (c) The angle between the scapular spine and clavicle is increased by about 10° and is produced by an anti-clockwise rotation of the scapula around a vertical axis through the acromioclavicular joint.

Phase 3 (The arm is elevated from the end of phase 1 to 90° of flexion or abduction). The following movements take place in addition to the movement at the GHJ: (a) Further elevation of the distal end of the clavicle about 30-36°, (b) No change in the spinoclavicular angle, (c) Scapular rotation in the anteroposterior axis takes place in 2:1 ratio; for each 10° of glenohumeral movement, 5° of rotation takes place. (d) Rotation of the clavicle in its long axis has not yet commenced.

Phase 4 (The arm is more elevated overhead from end of phase 3): (a) Scapulohumeral rhythm continues in the same 2:1 ratio. (b) No further elevation of the clavicle takes place. (c) Second part of rotation of the scapula around vertical axis by about 10° of protraction (total increase in spinoclavicular angle is thus 20°), (d) Clavicular rotation in crankshaft fashion with conoid tubercle pointing downward about 30-40° has now taken place. (e) External rotation of the humeral head is necessary if elevation is undertaken in coronal plane.

First Phase → **Scapular Setting (SS)[4]**

Important

Following SS, the motion occurs mainly at the SCJ and contributes directly to shoulder girdle motion.

Upward rotation of 5° – 15° occurs at the ACJ and STA

It is a preparatory rotation of shoulder girdle. It increases tension at the AC and CC ligaments. The clavicle and scapula moves together as a single piece[4].

SS lasts for the first 30° of GHJ abduction in coronal plane.	SS lasts for the first 60° of GHJ flexion in sagittal plane.

Second Phase → **Elevation of Clavicle[13]**

Important

ICR is located to the route of scapular spine until humerus reaches to 100°[8].

Elevation of the lateral aspect of the clavicle about <10° to 45°, coupled with upward rotation of the scapula. This elevation occurs at SCJ and associates with 100° of arm elevation. External rotation of the humerus at GHJ starts and continues to end-range of arm elevation[2,9,4,5].

Third Phase → **Posterior Tilt of Scapula & Further Upward Rotation**

Important

ICR is transferred to the ACJ as CC ligament is tight and no further elevation occurs at the clavicle[8,9].

The scapular posterior tilt occurs between 70° and 90° of arm elevation and end-range of overhead motion, a result of 30° to 50° posterior axial rotation of the clavicle. Further upward rotation of the scapula to 60°[4].

Advantage
Subacromial space is widened[5]. Clear the humeral head and rotator cuff tendons from beneath the anterior rim of the acromion.

Fourth Phase → **Further Clearance of Acromion**

Up to 70° of external rotation of the humerus[5], associated with 15° – 35° of external rotation of the scapula[4].

Advantage
Clear the greater tuberosity from beneath the acromion[5]

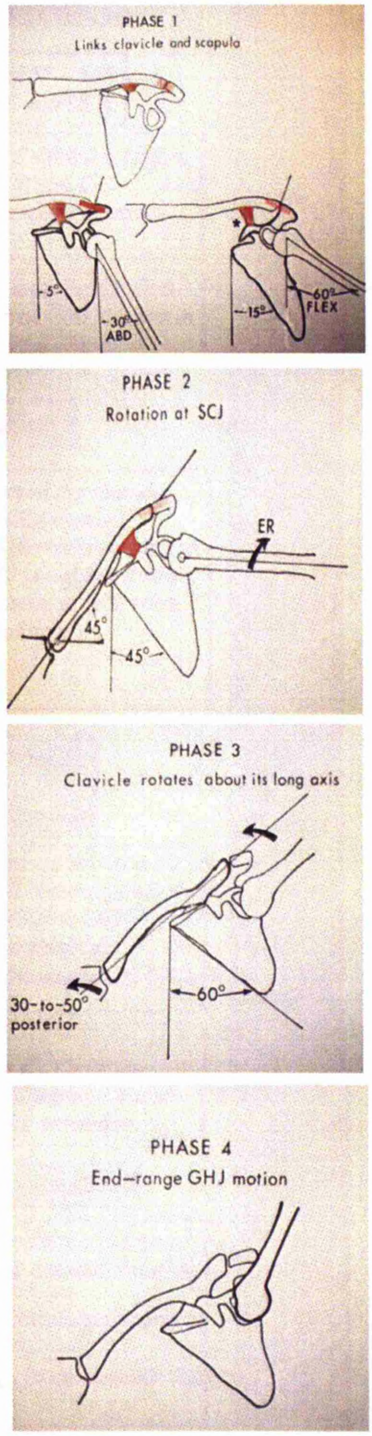


Figure 2 - 1: Kinematic phases of forward arm elevation and overhead reaching (adapted from[92])

SCJ: sternoclavicular joint, STA: scapulothoracic articulation, AC and CC ligaments: acromioclavicular and coracoclavicular ligaments, ICR: Instantaneous Centre of Rotation, it refers to the changeable centre of upward rotation of scapula during arm elevation.

Various methods have been used for kinematic analysis of the shoulder joint. However, each of these methods has limitations and disadvantages that have not yet been resolved. Hurov (2009)[92] reviewed shoulder kinematics during overhead motion and brought into view that a concomitant motion of the scapula, clavicle and humerus was observed with different amplitudes of joint motion dependent on several variables such as age, gender, rate of motion, measurement techniques and specific tasks performed[92].

The motor and neuronal control systems are facilitated by the tensioning of acromioclavicular and coracoclavicular ligaments that link together the clavicle and scapula to make a single bone-like shoulder girdle which moves only at the sternoclavicular joint and STA during the initial 90-100° of GHJ flexion[92]. The 'scapulohumeral rhythm' delineates the patterned upper extremity elevation in GH and scapulothoracic joints. Several authors documented remarkable differences during overhead reaching in the direct recordings of GHJ and STA motion[4,118].

Matsuki and colleagues (2011)[119] compared the scapular motion in both the dominant and non-dominant arms in 12 healthy subjects, using 3D analysis, and concluded that scapular motion was dissimilar between dominant and non-dominant arms. The dominant scapula was rotated further downward at rest and reached greater upward rotation with abduction[119]. These differences should be considered in clinical assessment of shoulder pathology, for example, using the lateral scapular slide test (LSST) to assess the scapular resting positions and scapular position at 45° and 90° of arm abduction[120].

2.5.1 Scapular Muscle Function and Scapular Positioning

The Axio-scapular muscles are primarily responsible for scapular stability and multidirectional scapula gliding. In the initial phase of arm elevation, the UT and lower SA coordinate their activity in order to rotate the scapula upward in a force coupling mechanism[121,73,122]. In the mid-range of arm elevation as the arm approaches 70-90°, the SA and LT increases their contribution for further upward rotation and posterior tilt of the scapula[5,123]. Towards the end-range of arm elevation the SA, UT and LT are equally active[121,73]. Posterior tilt and external rotation of the scapula require further investigation[61]. The RM and LS are primary stabilizers of the scapula and function as scapular adductors (retractors), downward rotators and elevators.

2.5.2 Muscles Crossing the Glenohumeral Joint and Centring of the Humeral Head

The rotator cuff muscles, including the SSP, ISP, Tm and SUBS, maintain the congruent contact between the humeral head and the glenoid fossa, as described in GHJ stability (Section 2.3.2). The LD and TM in addition to the ISP, SUBS and BB act as depressors and minimize upward and anterior translations of the humeral head during mid-range of arm elevation[124].

2.5.3 The Deltoid Muscle

The deltoid muscle also functions with the SSP muscle to produce a smooth elevation of the humerus during all phases of GHJ elevation[125,4,126]. However, after the initial 30-60° of arm elevation, the SSP becomes less effective and the deltoid becomes the major contributor to this action[10]. Kronberg (1990)[127] and others emphasized the importance of deltoid and SSP as primary abductors of the shoulder[127-130]. Based on a cadaveric model representing upper limb anthropometry and muscle lines-of-action, Jay and Ackland showed the capacity of deltoid and rotator cuff muscles to accelerate the glenohumeral joint when the elbow is in flexion[131]. Although several studies on the shoulder complex consider upper limb motion with the elbow full extended[125,129,132], elbow flexion is required during most activities of daily living[133].

2.6 Normal Variations in the Assessment of Shoulder Function

Different measurements are used to assess shoulder function, including range of motion, muscle strength, functional performance, posture and self-reported function and quality of health. It is important to understand the relationship between various measurements of function/disability in persons without shoulder problems and tent of deficit or recovery.

2.6.1 The Range of Motion

Studies on range of motion (ROM) and its relationships to age, gender and dominance revealed conflicting results[134-136]. Gender-related effects were described with minimal differences by Murray et al. (1985)[137], while Barnes et al. (2001)[135] observed greater ROM in women than men. Women had a significantly higher range of motion than men in external rotation within 40-59 year age group[138]. Subjects over 60 years experienced a decreased ROM but not in all shoulder movements[135]. However, the specific shoulder movements affected by age are inconsistent between studies. Joint mobility among normal individuals varies widely between different ethnic groups. Negroes and Indians have a greater range of joint movement than Caucasians[139]. Age and sex variations have also been recorded[140]. Diminished joint mobility becomes pronounced with ageing. Females have a greater degree of joint laxity than males of the same age. Kirk et al. (1967)[141] reported musculoskeletal complaints in individuals with joint hyperlaxity but no other findings of hereditary connective tissue disorders. Al-Rawi et al. (1985)[140] found greater joint hyperlaxity in Iraqi university students compared to retrospective groups of other nationalities [Table 2 – 3].

Table 2 - 3: Mobility scores in 103 female UK University students compared to similar data in 587 Iraqi University students[140].

Joint hypermobility level was given a score between 0 and 9 utilising the methodology illustrated by Beighton (1973)[142]. A sore between 0 and 3 (group A) indicated no sign of joint hypermobility (normal). A score between 4 and 6 (group B) as well as 7 and 9 (group C) were representative of varying grades of joint hypermobility.

	Group A (scores of 0-3)	Group B (scores of 4-6)	Group C (scores of 7-9)
UK females	72/103 (69.9%)	25/103 (24.3%)	6/103 (5.8%)
Iraqi females	361/587 (61.5%)	185/587 (31.5%)	41/587 (7.0%)

Al-Rawi et al. (1985)[140] used the scoring system illustrated by Beighton (1973)[142], who used a modification of the Carter and Wilkinson grading system[143]. Patients were provided with a 0-9 numerical score for the assessment of joint hypermobility degree. One point was given for the competence to complete each of these tests: (1) The little finger passive dorsiflexion beyond 90°. (2) The thumb passive apposition to the forearm flexor aspects. (3) The elbow hyperextension beyond 100°. (4) The knee hyperextension beyond 10°. (5) The trunk forward flexion with the knees in a straight position, hence allowing the palms of the hands to rest on the floor. Furthermore, the association between the arthralgic symptoms and joint mobility as well as musculoskeletal symptoms was assessed using a scale of 0 to 4. A single point was allocated for each positive answer to questions regarding the feeling of (1) pains in the hands or feet, (2) other joint pains, (3) other pains in the limbs apart from those in hands, feet and joints and (4) backache[142].

A score of 4 out of 9 or higher was indicative of joint hypermobility and was found in 38.5% of Iraqi female students compared to 30.1% of UK females [Table 2 - 3]. This indicated a higher level of joint hyperlaxity in Iraqi students in comparison with the corresponding UK group. In addition, a clear correlation between joint hypermobility and flat feet, high palate, ligamentous sprains, Raynaud's phenomenon, joint complaints, varicose veins and easy bruising was observed in students with scores of 7 to 9 more than in subjects with no joint hypermobility (scores of 0-3)[140]. This correlation was also seen more frequently in Iraqi university students as opposed to UK students [Table 2 - 3][140].

2.6.2 Muscle strength

Lack of standardization in plane of motion, shoulder position or body stabilization has been attributed to the varying degrees of success to define normal values for strength of shoulder muscles[144]. Gender related differences exist in strength documenting men stronger than women by age and weight[138,145]. An age-related decline has been observed above 60 years in strength of men. There was no significant correlation between strength and range of motion[138].

The effects of age and dominance are less well known. It was reported in the normal population, age is negatively associated with isometric shoulder strength with some rotational strength measurements differing between dominant and non-dominant sides[145,146,136]. During voluntary isometric contractions, right-handed subjects had a higher rate of fatigue in the non-dominant hand with a greater decrease in median frequency. Left-handed subjects exhibited no significant sided difference in median frequency behaviour which was attributed to a high ambidexterity level[147]. Daily preferential use was shown to alter physiological and mechanical properties of skeletal muscle. Lower average firing rates, lower recruitment thresholds and greater firing rate/force delay in the dominant hand was reported in the preferentially used muscle. It was attributed to a lifetime of preferred use causing adaptations in fibre composition of dominant muscle and increasing the mechanical effectiveness of motor units[148]. Other authors found no differences in the motor and sensory nerve conduction velocities for the right and left arm in right-and left-handed subjects[149].

2.6.3 Posture

Cureton (1941)[150] was probably the first to quantitatively document the postural relations of the head and shoulders of young men using photographic measurements[151]. The physical appearance of the head, neck and shoulders is a principal subject in the debate of human posture[152]. Evaluation of head and shoulder posture has been commonly considered the profile alignment of body parts with respect to the trunk. Other postural correlates were described without quantitative verification, as a forward head related to an extended upper cervical spine, or to protracted shoulder girdles and a kyphotic thoracic spine, or less widely of hand preference being related to coronal plane shoulder asymmetry[153]. The data on age related anterior tilt of the head in respect to the trunk in the sagittal plane is conflicting and with very limited with objective measurements. Raine and Twomey (1997)[154], who reported head and shoulder posture variations in 160 healthy women and men, found that age was not significantly related to the tilt of the head in the sagittal plane.

The effect of gender on head posture is still unclear but both sexes demonstrate a more forward head position[155]. Raine and Twomey (1997)[154] reported that head and shoulder posture was similar between genders. Limited information is available on gender effect with shoulder alignment but baseline data indicates women to be more round-shouldered than men[156]. A relation between the sagittal plane features of a forward head, forward shoulders, and increased thoracic kyphosis has also been described anecdotally in the literature but no significant statistical correlations have been demonstrated[154,151].

2.7 Prevalence

Pain in the shoulder region is a common musculoskeletal problem affecting approximately 10% to 40% of the population[36,34,157]. Approximately 54% of patients report ongoing pain after 3 years[48]. In The Netherlands, a large population survey of musculoskeletal symptoms revealed 21% of respondents were suffering from shoulder pain at the time of questioning[36]. The British Tameside study found a lower but still substantial estimated prevalence of 14%[34]. In several countries, the one year prevalence is estimated to be 20-50% and the lifetime prevalence is one in three[158]. Only about 40-50% of people with shoulder pain consult a primary care physician or general practitioner. Studies from primary care show that one year after a first consultation, 50% of patients report that their symptoms have persisted or recurred[37].

The most frequent cause of shoulder pain is SIS accounting for 44 to 60% of all complaints of shoulder pain seen in a visit to a doctor[37,38]. SIS is also one of the major causes of chronic disability in the shoulder[46]. Moreover, approximately one-fifth of all disability payments are for patients with shoulder disorders[159]. Swedish insurance data shows that 18% of disability payments made for musculoskeletal disorders was spent on neck and shoulder problems[159]. Roquelaure and colleagues (2006)[160] conducted an epidemiological surveillance of upper-extremity musculoskeletal disorders in France and identified SIS as the most common upper extremity painful condition in the working population.

Based on shoulder activities in work and sports, further epidemiological studies have revealed a prevalence of impingement of 5–20% in some occupations including welders, plate workers and slaughterhouse workers[161], and a prevalence among competitive overhead athletes of 10–30%[162]. Musculoskeletal complaints in the neck-shoulder region increase with age and are reported by women more commonly than men[163]. However, Milgrom et al. (1995)[164] found no statistically significant difference in the incidence of impingement findings between dominant and non-dominant arms or between genders. Smokers and those exposed to previous smoking may develop shoulder pain, while heavy manual workers and those adopting a forward flexion posture for long hours are at high risk[165]. Thus, shoulder pain is widespread and imposes a considerable burden on the affected person and society.

2.8 Classification

Neer (1983)[81] proposed a staging system, progressing from a reversible lesion, to a frank partial or complete tear of the rotator cuff [Table 2 - 4]. It was later realized that impingement in patients aged younger than 50 years may not be true impingement as defined by Neer's stages but secondary to instability[21].

However, almost 40 years after Neer's publication, the aetiology and pathogenesis of SIS still remains unclear and numerous authors[166,67] have challenged Neer's original claim. It appears that SIS is a multifactorial condition whose symptoms may be attributed to a large number of causes.

Table 2 - 4: A staging system of pathologic changes in impingement[81]

Stage	Age group	Pathologic change
I	Under 25 years	Oedema and haemorrhage in the rotator cuff tendon and bursa with overhead use in sports or work
II	25 – 40 years	Degeneration and fibrosis of the tendons and bursa.
III	Over 40 years	Bone spur
		Partial or full thickness tear of the rotator cuff tendon

In an attempt to develop a classification system with precise categorization of patients with shoulder impingement, several risk factors that interact and influence the pathogenesis of SIS should be considered [Figure 2 - 2]. These include:

(1) Environmental-related factors: Trauma, occupational, recreational and lifestyle risk factors are highly influenced by the surrounding environment.

(2) Individual Central factors: Central nervous system, the effect of ageing and pain are risk factors that affect motor control.

(3) Individual shoulder-related factors

   a. Intrinsic factors: A primary pathology starting in the rotator cuff muscles or biceps brachii tendons, for example, inflammatory or degenerative lesions.

   b. Extrinsic factors: Including anatomical (static) alterations as degenerative bony changes in the acromion, coracoacromial arch and acromioclavicular joint. Dynamic factors include alterations in scapulothoracic joint/GHJ kinematics, neuro-muscular activation imbalance and faulty posture.

2.9 Pathogenesis and Risk Factors of Subacromial Impingement Syndrome

2.9.1 Environmental Factors

2.9.1.1 Trauma

An identifiable traumatic event may be a presenting factor in patients with SIS and found more commonly in overhead athletes than in other patient groups. Some patients may report a major or trivial injury that precedes their shoulder pain, for example, direct impact on the shoulder, falling down on an outstretched hand, a neck injury or a seat-belt injury. Some patients with a whiplash injury may present later with shoulder pain and a group of them responds to the treatment of SIS if diagnosed early. That is not usual as the diagnosis is often overlooked and the pain at the shoulder is attributed to the neck[167,168]. Abbassian and Giddins (2008)[169] reported that 26% of 220 patients with whiplash injury had developed shoulder pain and 5% were treated for SIS.

2.9.1.2 Overuse

Athletes are frequently challenging their own capacity with an attempt to achieve higher performance. They may expose their muscles and tendons to extreme tension. If the rotator cuff is directly involved, inflammation and oedema may follow to compromise the potential subacromial space leading to friction with the acromion and coracoacromial arch and SIS ensues[170,63]. In tennis players, shoulder motion is highly dynamic and exceeds the physiological limits that may lead to dysfunction of the scapular and scapulohumeral muscles either due to direct injury or secondary to pain induced muscular inhibition[171]. Further inflexibility, weakness and imbalance of the muscles may lead to scapular dyskinesis in tennis players[172,173]. Resistance training exercises with the rotator cuff in unfavourable positions during pushing or lifting may induce shoulder injury, joint instability and muscle imbalance that may lead to further shoulder dysfunction[174,175] .

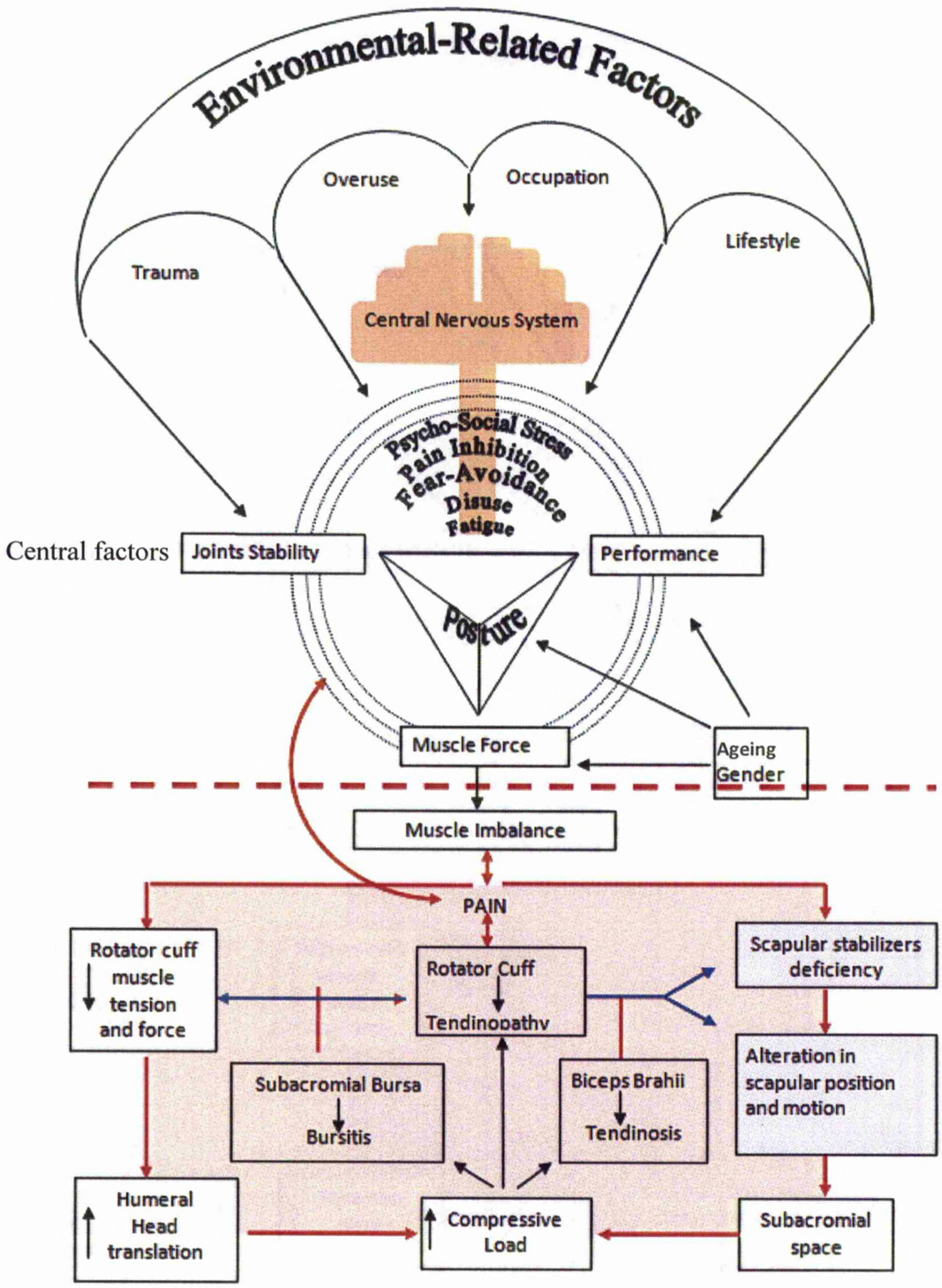


Figure 2 - 2: Risk factors that interact and influence the pathogenesis of subacromial impingement syndrome

2.9.1.3 Occupation

In a systematic review of 29 studies, van der Windt and his colleagues (2000)[176] identified two groups of occupational-related risks for shoulder pain. The physical risk factors included carrying or lifting heavy loads, working in awkward postures, engaging in repetitive movements, being exposed to vibrations and performing similar work for prolonged periods. In certain occupations of heavy manual and repetitive work the risk developing SIS approaches 5-20%. Psychosocial risk factors included mental stress, job pressure, control at work, social support, and job satisfaction. Nearly all studies that assessed work related psychosocial risk factors reported at least one positive association with shoulder pain.

2.9.1.4 Lifestyle

Environment and lifestyle are far more important than genetics in regard to functional performance and ageing. A direct relationship exists among negative lifestyle choices, shoulder pain and loss of function. Buchman and colleagues (2007)[177] suggest that higher levels of physical activity are associated with a slower decline rate of motor performance in older people. Kane et al. (2006)[178] found a significant correlation between cigarette smoking and microscopic changes in the rotator cuff. In 2010, Kane and colleagues[179] emphasized the relationship between cigarette smoking as well as elevated cholesterol and reduced function of the shoulder. If an association between lifestyle and shoulder function could be shown, then behavioural modifications may be able to prevent some types of shoulder pathology and thereby improve a patient's shoulder health and quality of life.

2.9.2 Central Factors

2.9.2.1 Motor System

The importance of the central nervous system (CNS) is reflected by the neurological predisposition of muscles to exhibit predictable changes in tone, and the importance of proprioception and afferent information in the regulation of muscle tone and movement. Therefore, chronic musculoskeletal pain requires integrated functional assessment and treatment that focus on the sensorimotor system rather than the musculoskeletal system itself[180]. Additionally, the human body maintains homeostasis by inducing compensations and adaptations not only at the site of changes but also elsewhere in the system[181]. Some studies on the timing or onset of muscle recruitment demonstrated alterations in the unaffected as well as the painful shoulder[182,73], indicating the possibility of a system integrated response[48]. In response to pain or damage, signals from nociceptive receptors may influence both peripheral and central motor, which in turn lead to changes in muscle tone. For example, experimental muscle pain involving the UT induces reorganization in the coordinated activity of the three subdivisions of the trapezius in repetitive dynamic tasks[183].

Further supportive evidence of the involvement of the central nervous system in the pathogenesis of SIS is the growing research suggesting that referred pain, hypersensitivity to peripheral stimuli and neuropathic pain in patients with SIS represents peripheral manifestations of 'central sensitisation'[184], which will be elaborated in the section of pain (section 2.9.2.3).

2.9.2.2 Ageing

Ageing is an inevitable process associated with decline in function. The muscle strength and bone mass may show gradual decrease in their properties by the fourth decade of life, as physical reserves likewise decline. In general, function and independence decrease when the demands of the task outstrip the individual's reserves. The annual decline in muscle strength of the elderly ranged from 1.4 to 5.45%, depending on the muscle group and the angular velocity[185-188].

In contrast to type I muscle fibres and capillarization, reduction in muscle strength and area of type II muscle fibres have been reported with ageing[189]. Variations in percentage of reduction are widely observed in the literature. Motor performance reflects the function of a large number of cortical and subcortical structures necessary for the planning and execution of movements, whereas muscle strength may predominantly reflect motor unit and muscle function[177]. Although the causes of age-related motor decline are poorly understood, Frontera (2003)[168] and Buchman (2007)[160] highlighted the significance of physical activity as a modifiable risk factor and demonstrated that higher physical activity slows the reduction rate of motor control and muscle functionality in the elderly.

2.9.2.3 Pain

Functional implications of pain are evident from daily life, where pain from joints and muscles affects motor performance. Potentially, the interactions of pain to motor function and motor function to pain are interconnected in a mechanistic manner.

Central Sensitisation: A high proportion of patients with impingement awaiting subacromial decompression have referred pain, paraesthesia and increased sensitivity to pain radiating distally to the forearm[190]. In more than a half of those patients, this neural type of pain resolves following successful decompression[191]. This type of pain represents a peripheral manifestation of augmented central pain processing, 'central sensitisation'[184]. The presence of free nerve endings containing substance P and calcitonin gene-related peptides in the subacromial space may be the source of the nociceptive outputs[192]. These observations confirm the presence of central sensitisation in a higher number of patients with shoulder pain associated with impingement[193].

Muscle activity strategy: Pain may induce alterations in the strategy and coordination of muscle activity. Experimentally induced pain studies revealed the alterations of muscle activity in response to induced acute pain[194,195]. Injection of 5% hypertonic saline into the supraspinatus muscle produced a significant decrease in activity of the AD, UT and infraspinatus, but an increase in the activity of LT and LD muscles during abduction, a strategy aimed to reduce tension on supraspinatus muscle[196]. An increased muscle activity was also seen in the LT, SA and LD muscles following subacromial injection with 5% hypertonic saline[196]. Bandholm and colleagues (2006)[47] documented a reduction in isometric force generation of shoulder abduction in patients with SIS with changes in shoulder abduction muscle activation strategy in some patients. In 2008, Bandholm and colleagues[197] induced experimental pain in the shoulders of 9 healthy subjects. They found a similar reduction in isometric force generation of the shoulder abduction between SIS patients and the healthy subjects, while the EMG alterations in muscle activation were different. "A possible explanation is that even though the adopted experimental pain-paradigm may reflect the SIS in terms of the painful structures, but it might not reflect the adaptations in the central nervous system seen with chronic pain" (Bandholm et al., 2008, p. 643)[197].

Models of Pain–Motor Interaction: The dysfunction that occurs in the neuromuscular system in the presence of pain is extremely complex. It is not clear whether shoulder motor function impairment in SIS patients is due to the pain condition per se, or the pathological/inflammatory changes, or disuse of the affected shoulder. Hence, musculoskeletal pain has been proposed by several authors to disturb motor control and several models have been proposed in an attempt of clarification. The 'vicious cycle model' is characterized by enhanced activity of the muscle spindle system, muscle spasm, metabolite production, more pain, further increased hyperactivity and stiffness which continues as a vicious circle[198,199]. A second model involves a decreased rather than increased activity in the affected muscle, while EMG shows evidence of some hyperactivity in the antagonist muscle 'pain-adaptation model'[22]. The third one shows loss of selective activation and inhibition of certain muscles that perform key synergistic functions, leading to altered patterns of neuromuscular activation 'neuromuscular activation model'.

Chronic pain patients frequently display pain behaviours and functional disability at a level far exceeding that to be predicted on the basis of known organic pathology. Furthermore, pain-related fear and avoidance are important features that lead to the development of chronic problems such as refusal to move, progressive weakness and stiffness in patients with musculoskeletal pain. Lethem and his colleagues (1983)[29] described a fear-avoidance model explaining that confrontation leads to the fear reduction with time and avoidance maintains and exacerbates fear leading to a phobic condition. Subsequently attention has been directed toward psychological factors involved in the development and continuation of fear and chronic pain problems[200].

Depression is observed to be a frequent companion to a chronic pain syndrome[201]. Depressed individuals are often noticed to complain of various pain types[202] and the severity is a predictor of poor treatment response for chronic pain[203].

2.9.2.4 Muscle Imbalance

The relationship between individual muscles or groups of muscles in terms of contraction and coordinated muscle activity are maintained within normal variable limits in order to maintain stability and function. Impairment in this relationship due to sensorimotor disorders may lead to muscle imbalance and dysfunction[204-206]. Ageing, weakness, fatigability, overuse injury, pain inhibition and several systemic disorders may lead muscle imbalance[193]. The result is either a diminished participation of the other muscle that leads to disuse atrophy, or excessive motion in the direction of another action produced by the dominant muscle[207]. Muscle imbalance is increasingly recognised in the aetiology of SIS. The coupling forces, for example between trapezius, SA, LS and rhomboids, which maintain the stability of the scapula and its controlled movement with the humerus may be impaired because of muscle imbalance. The scapula reveals alterations in its upward rotation, posterior tilt and external rotation leading to narrowing of the subacromial space and impingement[32,208,16]. Poor movement habits and faulty postures also predispose to shoulder impingement because of alterations on the tensile forces of the muscle and muscle imbalance, for example, increased activity in UT and reduced activity in SA[209,210].

2.9.3 Local Factors

Other local intrinsic and extrinsic factors were reviewed in the literature and summarised in Table 2 - 5.

Table 2 - 5: Local factors in the pathogenesis of SIS

Category and Sub-Category	Reference
Intrinsic Factors	
1. Rotator cuff overuse	Jobe and Jobe (1983)[211] Meister and Andrews (1993)[212]
2. Rotator cuff degenerative tendinopathy	Ozaki et al. (1988)[213]
Extrinsic Factors	
1. Primary impingement	
a. Acromial bone spurs	Neer (1972)[46]
b. Os acromiale	Edelson , et al. (1993)[214] Hutchinson et al. (1993)[84]
c. Coracoacromial ligament	Soslowsky et al. (1994)[215]
d. Posterosuperior glenoid impingement	Jobe, et al. (1997)[166] Riand, et al. (1998)[216]
2. Secondary impingement	
a. Secondary tensile disease	Meister and Andrews (1993)[212]
b. Secondary compressive impingement	Warner et al. (1990)[68]
c. Restricted glenohumeral capsule	Harryman et al. (1990)[74] Matsen and Arntz (1990)[217]
d. Functional scapular instability (scapular dyskinesia, muscle imbalance)	Kibler (1991)[218] Kibler, et al. (1998)[18] Warner et al. (1992)[219]
e. Posture	Ayub (1991)[220] Bowling et al. (1986)[209] Cailliet, (1991)[207] Solem-Bertoft el al. (1993)[72]

2.10 Pathomechanics of the Scapulothoracic Articulation

One or several factors of those described in section 2.9 could be involved to produce alterations in the normal mechanics of the scapulothoracic articulation (STA) as illustrated in Figure 2 - 3.

Shoulder

At or around the shoulder joint

Any painful condition
Lund et al. (1991)[22]
Lethem et al. (1983)[29]
Verbunt et al. (2005)[30]

Physical stress
Repetitive motion
Cohen (1998)[17]

Affinity to / induced fatigue
Chopp et al. (2011)[24]

Weakness / Imbalance

Alterations in GHJ stabilizers and movers
(See section 2.10)

Alterations in function of scapular-positioning muscles
Kibler (1998)[18]
Kuhn (1995)[26]

Proprioceptive deficit
Machner et al. (2003)[6]

A decrease in position sense leading to impaired coordination
Voight et al. (2000)[15]
Carpenter et al. (1998)[28]

- Abnormal positioning of the scapula
- Disturbances in the SHR
- Scapula glides more laterally
- Shoulder dysfunction 'Dyskinesis'

Kamkar et al. (1993)[25]

Lower stabilizers of the scapula mostly weak or inhibited
SA, RM, LT, MT
Voight et al. (2000)[15]

During both GHJ flexion and abduction, deficit in SA and LT force coupling lead to decrease in one or more of the following:

- Scapular upward rotation
  Ludewig and Cook (2000)[19]
- Scapular posterior tilt
  Ludewig and Cook (2000)[19]
  Lukasiewicz et al., (1999)[32]
- Scapular external rotation
  Ludewig and Cook (2000)[19]
- Acromial clearance
- Shoulder abduction

secondary impingement
Kamkar et al. (1993)[25]

Scapular dysfunction leading to further shoulder injury
Kibler (1998)[18]
Kuhn et al. (1995)[26]
Glousman et al. (1988)[221]
Chopp et al. (2011)[24]

Figure 2 - 3: Scapulothoracic articulation (STA) pathomechanics could lead to subacromial impingement syndrome.
GHJ= glenohumeral joint, SHR= scapulohumeral rhythm, SA= serratus anterior, RM= rhomboid major, LT= lower trapezius, MT= middle trapezius.

2.11 Pathomechanics of the Glenohumeral Joint

The alterations in the mechanics of the GHJ are precipitated by a single or several pathogenic and risk factors (section 2.9). In addition, any change in normal STA control leads to insufficient tension in the muscles crossing the GHJ, poor force coupling control, humeral head translation and loss of centring. Thus, these are leading to serratus anterior muscle space narrowing, impingement and further abnormal GHJ movements [Figure 2 - 4].

Shoulder

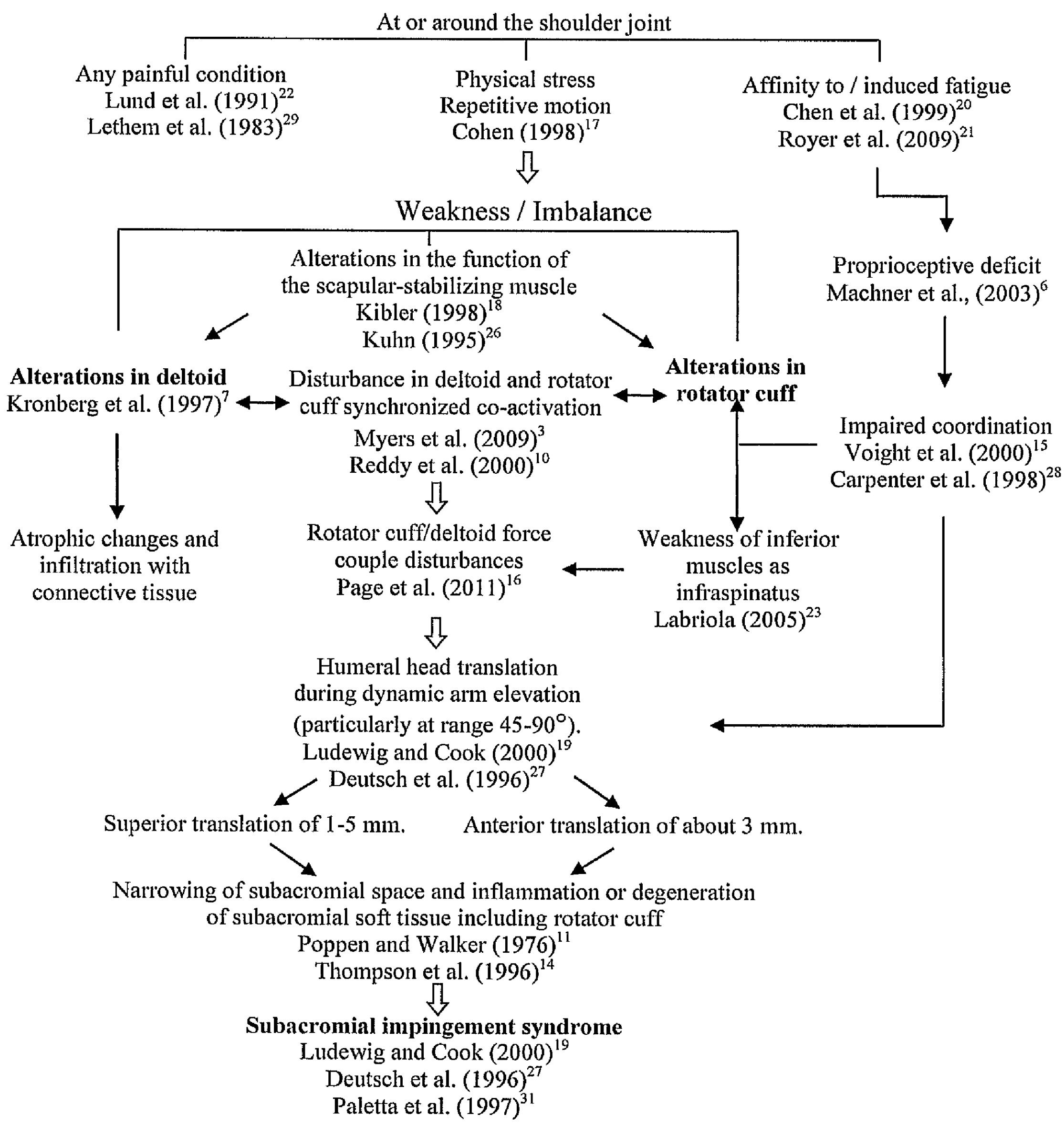


Figure 2 - 4: Glenohumeral joint (GHJ) pathomechanics leading to subacromial impingement syndrome.

2.12 Upper Body Posture

Forward head posture (FHP), forward shoulder posture (FSP)[222] and altered scapular kinematics and muscle activity[19] were reported in patients with SIS [Figure 2 - 5].

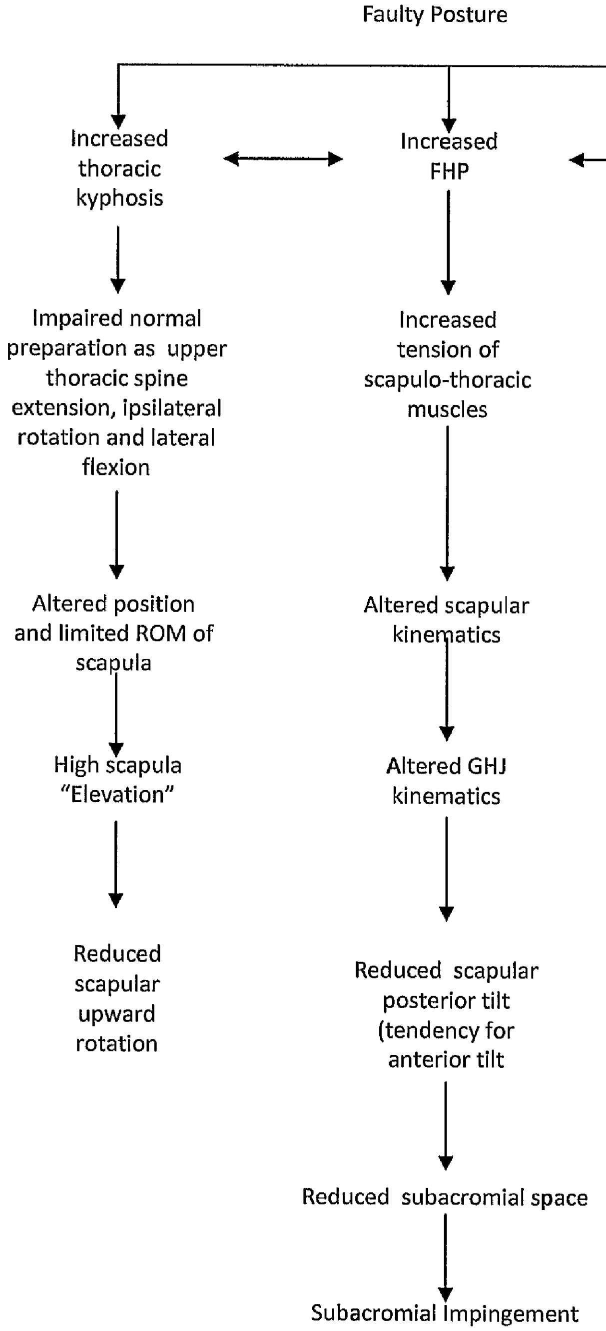


Figure 2 - 5: Progressed faulty posture and changes leading to subacromial impingement syndrome.

FHP= forward head posture, FSP=, forward shoulder posture, ROM= range of motion, GHJ= glenohumeral joint.

2.13 Clinical Assessment

SIS is a common diagnosis, but it is probably over-diagnosed as the primary aetiology of pain in the anterosuperior part of the shoulder. The accurate diagnosis is mandatory though may be difficult because the anatomy and function of the shoulder are complex and the clinical presentation may be highly variable[65]. The clinical decision-making depends on a thorough collection of subjective data and objective findings in order to establish good differential diagnosis of functional impairment of the shoulder and reach a well-defined diagnosis in patients with functional impairments of the shoulder[223].

2.13.1 History

Impingement syndrome is more common over the age of forty years. In younger patients, shoulder pain may be associated with subtle instability of the GHJ; therefore diagnosis must be made with caution[170]. The occupation, handedness of the patient, the onset, duration, timing, severity, quality, exacerbation, and relief of the symptoms are important differentiating factors.

Table 2 - 6: History and physical examination of patients with subacromial impingement syndrome.

Characteristics of pain	**Clinical Examination**
Onset and Duration • Insidious onset • Chronic progress during several months.	LOOK (from front, side and back) Scars, discoloration, swelling, prominence, deformity and muscle atrophy.
Position of maximal pain • Anterior to acromion • Lateral to acromion	FEEL Specific points of tenderness (for example: ACJ and anterior to acromion)
Character • Dull, aching, pricking • Severe, crunching, stabbing	MOVE Flexion, extension, abduction, horizontal adduction, internal and external rotation are assessed for limited range and asymmetry in motion during: Active ROM Passive ROM
Timing • Day-time pain • Night pain	TEST for muscle strength Manual tests for muscle strength Using a myometer for isometric or isokinetic contraction
Aggravating factors • Movements during daily activity, job and recreation.	SPECIFIC TESTS Tests for impingement and disintegrated RC Tests for labral deficit and tendonitis of long head of biceps Tests for GHJ instability.
Relieving factors • Reduced activity and rest	

2.13.1.1 Pain

Shoulder pain is the most common symptom of SIS[81,224,82,65]. A good history-taking of pain is very helpful to approach the diagnosis. Important characteristics of pain including the onset, duration, position of maximum pain, pain character, timing, aggravating and relieving factors [Table 2 - 6]. Night pain, which is related to increased pressure in the subacromial space[225] is typical, while daytime pain is related to arm elevation and overhead activities[226]. The structures most often irritated and inflamed with SIS are the rotator cuff muscles, the long head of the biceps, the subacromial bursa. Pain that originates from pathology in these subacromial structures tends to be difficult to localise, is usually felt in the deltoid region and may radiate to the arm as far as the elbow[227]. It is usually elicited between 70 and 120° of abduction[65]. This sector is called the 'painful arc' [Figure 2 - 6][1].

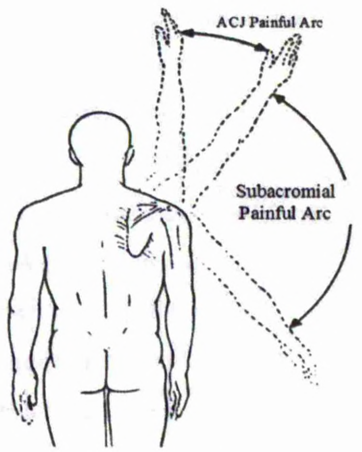


Figure 2 - 6: Painful Arc (taken from[1,2])

2.13.1.2 Weakness and Loss of Motion

Weakness and loss of motion of the shoulder may also be present, but these symptoms are usually secondary to pain[65]. Pain caused by impingement may also propagate weakness by reflex inhibition of the muscles and wasting. However, it has been verified by isokinetic strength measurements that prolonged impingement syndrome leads to a real decrease in shoulder muscle strength[69,228].

2.13.2 Clinical Examination

The systematic shoulder examination includes look, feel, move and test as a routine approach in every patient and usually extends to assess the cervical spine, upper extremity and neurovascular status [Table 2 – 4]. Clinical examination, although having great importance, may not be sufficient for appropriate diagnosis. Clinical tests for the shoulder are sensitive but not specific for one particular shoulder condition[228,43]. The sensitivity of diagnosis of SIS by physical examination was 73% in 45 patients with shoulder pain who had the certain diagnosis by arthroscopy[229]. More than 20 clinical diagnostic tests exist in clinical practice to approach the diagnosis of SIS [Table 2 - 7, 2 – 8 and 2 – 9]. However, we found only a few studies investigating diagnostic accuracy of these tests in the literature[228,230,231,43].

2.13.3 Muscle Strength (Isometric Maximum Voluntary Contraction)

Muscle strength is the ability to develop tension by a muscle during muscle contraction irrespective of the mode of testing (isometric, isotonic or isokinetic contraction), the muscular contractile velocity (slow vs. fast), or the type of muscle contraction (isometric, concentric, eccentric). Musculoskeletal disorders have been identified as one of the major risk factors for long-term sickness absence[232]. Shoulder impingement is usually associated with muscle weakness that may be related to pain or disuse atrophy rather than RC tear[233,234]. The association between muscle strength and musculoskeletal disorders, such as low back and neck/shoulder symptoms has been reported[235]. Men have higher muscle mass and are stronger than women, which predicts the possibility of higher susceptibility of women to musculoskeletal disorders. On the contrary, other studies have not found a protective effect of high muscle strength on musculoskeletal disorders[236], as well as men show a greater loss of skeletal muscle mass with ageing as compared with women possibly due to hormonal factors including growth hormone, insulin-like growth factor, and androgens[237,238].

The most common indication for strength testing is to determine whether, and to what extent, myoneural dysfunction exists. Manual muscle testing, though claimed for its subjectivity, is still widely used today to assist in patient assessment and diagnosis[239]. Objective assessment of strength provides information on integrity and function of the RC and is used to gauge the recovery of muscle function following intervention.

Quantitative measures of isometric[240,241,144,239] and isokinetic[242,69] strength have been described to dictate the functionality of muscles in different muscle actions. Nottingham Mecmesin myometer is a reliable tool for measuring strength isometric contraction. A Cybex dynamometer is frequently used with isokinetic tasks. The importance of muscle strength has been confirmed in that shoulder strength has been shown to be related to general health status in persons with shoulder pathology. Celik and colleagues (2011)[49] evaluated twenty patients with mean age 48.15+/-5.9 years with Stage I (oedema and haemorrhage) and II (degeneration and fibrosis) SIS, as described by Neer (1983)[81], for the effect of pain on muscle strength. Using a handheld dynamometer, they found that middle trapezius, SA, supraspinatus and AD muscle strengths of the shoulder with positive impingement signs were significantly lower than in the healthy opposite side. The lower strength was highly correlated with the pain score using the self-reporting questionnaire Constant-Murley score (mean = 57.46), the visual analogue scale (VAS) (mean = 6.85), and face score in shoulders with SIS[243].

2.13.4 Clinical Tests

SIS exists as an association of various pathological processes around the shoulder each exhibiting different clinical signs and symptoms[65]. A meta-analysis on the accuracy of such tests indicates that physical examination may be useful at ruling out rotator cuff disorders (high sensitivity) but less accurate at specifying the exact structure at fault (low specificity)[244].

A clinical test should discriminate sick and healthy people to be called a diagnostic test. Table 2 – 7 indicates the clinical tests for SIS and RC tear. Many patients with SIS usually perceive pain when a compressing force is applied on or just proximal to the greater tuberosity of the humerus and rotator cuff region. Also pain may be aggravated with shoulder abduction in internal or external rotation. These manoeuvres constitute the basis of the Hawkins-Kennedy[245] and Neer[81] tests. Zachazewski et al. (1996)[246] reported that RC tendons were impinged under the acromion with Hawkins test and lower surface of the same tendons were impinged in anterosuperior part of glenoid margin with the Neer test. Ure et al. (1993)[229] found that Hawkins-Kennedy test sensitivity was 62% (specificity 69%), while Neer test sensitivity was 46% (specificity 62%) in 45 patients with stage II SIS, by comparing with arthroscopy. Hawkins-Kennedy test was suggested by Bak et al. (1997)[247] to have a higher sensitivity than Neer test for SIS. Murrell and Walton (2001)[248] prospectively studied 400 patients with and without rotator cuff tears. They performed twenty-three different clinical tests on each of the 400 patients, all of whom subsequently underwent arthroscopy. Only the tests for three clinical features were found to be more positive in patients with RC disease than in the control group (no tear) and were predictive for the disorder. These features were weakness in external rotation, weakness in abduction, and impingement (identified by a positive Neer or Hawkins-Kennedy tests)[248].

Park et al. (2005)[43] reviewed the different clinical tests used in the diagnosis of SIS and RC tear [Table 2 – 10]. The group reported the sensitivity and specificity of eight clinical tests[43] [Table 2 – 11]. Furthermore, Calis et al. (2000)[249] and Park et al. (2005)[43] reported the diagnostic accuracy for the combination of six [Table 2 - 12] and eight [Table 2 – 13] clinical tests respectively. Both studies concluded that combined tests can provide higher diagnostic accuracy (higher specificity) compared to individual clinical tests.

Many of the physical examination tests can be positive in the presence of other shoulder conditions, and the clinician should consider the results of the examination on the basis of the clinical presentation of the patient. The combinations of clinical tests are under investigation to show the most appropriate combination [Table 2 - 12 and Table 2 - 13]. It is clear that the Hawkins-Kennedy and Neer tests are quite efficient in diagnosis of SIS as they had high sensitivities. Moreover, accuracy ratio of these two tests was found to be higher than the other tests. However, their specificity values were lower than expected; hence, lessening their discrimination ability. Horizontal adduction test is used to assess the posterior tightness of the shoulder and compression of rotator cuff against the osteoarthritic acromioclavicular joint[250]. The test has been found sensitive to posterior tightness but unable to differentiate between capsular or rotator cuff tightness.

Yergason[251] and Speed[252] tests are commonly used to detect bicipital tendon disorders with or without SIS. In patients with stage I or II of impingement, repeated microtrauma or compression leads to haemorrhagic and oedematous changes in the long head of biceps. Biceps tendons may be thickened by fibrinoid degeneration in stage II SIS patients[249]. This may lead to over diagnosis of a primary bicipital tendinitis and subsequent over treatment. In a study by Young et al (2003)[253], an orthopaedic consultant and senior registrar each examined fifty patients with rotator cuff disease. They reported no significant difference between the findings of the two examiners for any of the signs studied, which included the drop-arm test, the Neer and the Hawkins-Kennedy impingement signs, weakness in abduction and external rotation, the painful arc sign, the Speed test, the Yergason test, and the Gerber lift-off test. Further clinical tests [Table 2 - 8 and Table 2 – 9] can be used to rule out other shoulder problems such as shoulder instability and lesions of the labrum. The details of the clinical tests were included in appendix III.

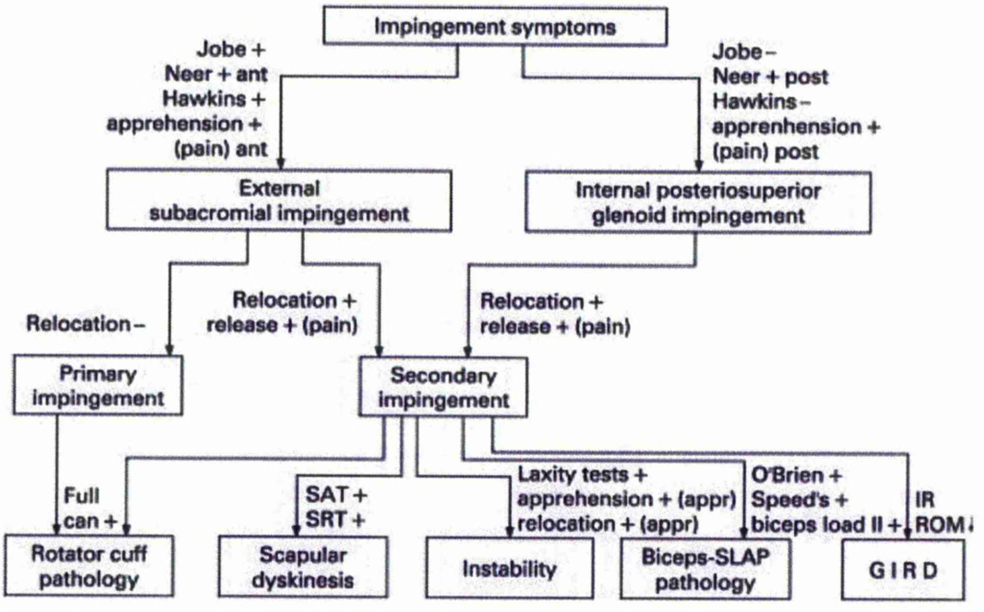


Figure 2 - 7: Algorithm for clinical reasoning in the examination of impingement related shoulder pain. (taken from[71])
(IR, internal rotation; GIRD, glenohumeral internal rotation deficit; ROM, range of motion; SLAP, superior labrum from anterior to posterior tear; SAT, scapular assistance test; SRT, scapular retraction test)

Table 2 - 7: Shoulder clinical tests for SIS and rotator cuff tears

Test	Positive response	References
Painful arc	Pain with or without catch at the arc of 60° to 120°	Adams (1955)[254] Kessel and Watson (1977)[1]
Hawkins	Pain located to the subacromial space Rotator Cuff	Hawkins and Kennedy (1980)[245]
Neer	Pain located to the subacromial space or anterior edge of acromion	Neer (1972)[46]
Drop arm	Arm drops indicating a full-thickness RC tear	
Lag sign external rotation (SSP + ISP)	A lag or angular drop occurs. The magnitude of the lag is recorded to the nearest 5°	Hertel et al. (1996)[255]
Drop sign	The arm drops down from 90° abducted position	
Lag sign internal rotation (SUBS)	A lag or angular drop	
Full cans (SSP strength)	Pain, muscle weakness or both	Kelly et al. (1996)[256] Itoi et al. (1999)[257]
Empty cans (SSP strength)	Pain, muscle weakness or both	Jobe et al. (1983)[211]
Internal rotation resistance strength test (IRRST)	Strong external rotation and weak internal rotation	Zaslav (2001)[258]
Lift-off (SUBS)	Inability to move the dorsum of the hand off the back	Gerber and Krushell (1991)[259]
Belly-press test (Napoleon test)	Unable to maintain the elbow at or anterior to the hand plane	Ambacher and Holz (2002)[260]

Table 2 - 8: Shoulder clinical tests for instability

Test	Positive response	References
Load and Shift	Mild 0-1cm translation Moderate 1-2 cm translation Severe >2 cm translation	Hawkins et al. (1988)[261]
Anterior Drawer Posterior Drawer	Relative movement between the fixed scapula and the movable humerus forward or backward	Gerber and Ganz (1984)[262]
Inferior Sulcus	I < 1cm II 1-2cm III > 2cn	Neer (1980)[263]
Apprehension Jobe Relocation	Apprehension as a patient response Relieve from apprehension	Jobe et al. (1989)[170]
Surprise / Release	Apprehension $\pm$ pain	Lo et al. (2004)[264]
Leffert	In instability, the examiner's index and middle fingers are separated as 90° abduction is approached	Leffert and Gumley (1987)[265]

Table 2 - 9: Shoulder clinical tests for superior labrum from anterior to posterior (SLAP) tear

Test	**Positive response**	**Paper**
Anterior Slide	Pain at anterior shoulder and /or pop or click in same area	Kibler (1995)[266]
Crank	Pain reproduced with or without a click or the symptoms are reproduced	Liu et al. (1996)[267]
SLAP-Prehension	Pain reproduced in the pronated position should decrease in supinated test position	Berg and Ciullo (1998)[268]
O'Brien's	Pain elicited when the arm internally rotated is reduced or eliminated when the arm in supination	O'Brien and Pagnani(1998)[269]
Pain Provocation	Pain is provoked only in the pronated position or when pain is more severe in this position	Mimori et al. (1999)[270]
Biceps Load 1	The active elbow flexion component of the test relieves the discomfort of the apprehension test for anterior instability	Kim et al. (1999)[271]
Biceps Load 2	Elicit pain	Kim et al. (2001)[272]
Yergasons	Pain at bicipital groove area	Yergason (1931)[251]
Speed	Pain is located to bicipital groove area	Bennett (1998)[252]

Table 2 - 10: Summary of the published reports on the diagnostic accuracy (DA: the percentage of patients who are accurately diagnosed as either affected or not affected by the disorder) of commonly used test for SIS[43].

The estimates of DA including sensitivity, specificity, PPV and NPV are calculated using the 2 x 2 table, where the clinical test findings (positive/negative) are plotted against the actual diagnosis[273]. They are determined by the following equations: Sensitivity (the population proportion that actually has the disorder and tests positive-true positive rate) = True positive/(True positive + False negative), specificity (the population proportion that does not have the disorder and tests negative-true negative rate) = True negative/(False positive + True negative), PPV (the proportion of subjects with a positive test result that is actually true positive) = True positive/(True positive + False positive), and NPV (proportion of people with a negative test result that is true negative) = True negative/(False negative + True negative). Overall DA is calculated as: (True positive + True negative)/(True positive + False positive + False negative + True negative)[273].

Study	Diagnosis	Diagnostic test	Sensitivity (%)	Specificity (%)	PPV* (%)	NPV† (%)	DA‡ (%)
Leroux et al. (1995)[228]	Impingement syndrome	Neer	89				
		Hawkins-Kennedy	87				
		Yocum	78				
Calis et al. (2000)[249]	Impingement syndrome	Neer	88.7	30.5	75.9	52.3	72
		Hawkins-Kennedy	92.1	25	75.2	56.2	72.8
		Horizontal adduction	82	27.7	73.7	38.4	66.4
		Speed	68.5	55.5	79.2	41.6	64.8
		Yergason	37	86.1	86.8	35.6	51.2
		Painful arc	32.5	80.5	80.5	32.5	46.4
		Drop arm	7.8	97.2	87.5	29.9	33.6
MacDonald et al. (2000)[230]	Bursitis	Neer	75	47.5	36	82.9	
		Hawkins-Kennedy	91.7	44.3	39.3	93.1	
		Neer /Hawkins-Kennedy	95.8	41	39	96	
		Neer + Hawkins-Kennedy	70.8	50.8	36.2	81.6	
	Rotator cuff pathosis	Neer	83.3	50.8	40 8	08.6	
		Hawkins-Kennedy	87.5	42.6	37.5	89.7	
		Neer or Hawkins-Kennedy	87.5	37.7	35.6	88.5	
		Neer + Hawkins-Kennedy	83.3	55.7	42.6	55.7	
	Bursitis/Rotator cuff tear	Neer	77.0	62.5	70.0	71.4	
		Hawkins-Kennedy	88.9	60.0	71.4	82.8	

Continued from Table 2-10[43]

Study	Diagnosis	Diagnostic test	Sensitivity(%)	Specificity (%)	PPV* (%)	NPV†(%)	DA(%)
Naredo et al.(2002)[274]	Supraspinatus lesion	Physical examination	79.3	50	95.8	14.2	
	Supraspinatus tendonitis	Physical examination	72.2	38.4	61.9	50.0	
	Supraspinatus tear	Physical examination	18.7	100	100	53.5	
	Infraspinatus lesion	Physical examination	70.5	90	85.7	70.5	
	Infraspinatus tendonitis	Physical examination	57.1	70.8	36.3	85	
	Infraspinatus tear	Physical examination	36.3	95	80	73	
	Subscapularis lesion	Physical examination	50	84.2	66.6	72.7	
	Subscapularis tendonitis	Physical examination	50	88	50	88	
	Subscapularis tear	Physical examination	50	95.4	75	87.5	
	Biceps tendonitis	Physical examination	73.6	58.3	73.6	58.3	
	Subacromial bursitis	Physical examination	42.8	88.2	75	65.2	
	ACCL§ involvement	Physical examination	58.3	85.7	93.3	37.5	
	Impingement	Physical examination	65	72.7	81.2	53.3	
Holtby and Razmjou (2004)[275]	Supraspinatus tendinitis or partial rotator cuff tear	Supraspinatus test	62	54			
	Full thickness cuff tear		41	70			
	Large to massive cuff tear		88	70			

*PPV = positive predictive value; †NPV = negative predictive value; §ACCL = acromiocoracoclavicular

Table 2 - 11: The diagnostic values of the eight clinical tests for impingement syndrome (taken from[43])*.

Clinical Test by Group	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
Group 1 (bursitis)				
Neer sign	85.7	49.2	20.9	95.7
Hawkins-Kennedy sign	75.7	44.5	17.4	92.2
Painful arc sign	70.6	46.9	12.3	93.8
Supraspinatus muscle test	25.0	66.9	8.8	87.4
Speed test	33.3	69.8	14.1	87.6
Cross-body adduction test	25.4	79.7	14.9	88.5
Drop-arm test	13.6	77.3	8.0	86.0
Infraspinatus muscle test	25.0	68.9	9.4	87.7
Group 2 (partial-thickness rotator cuff tear)				
Neer sign	75.4	47.5	18.1	92.6
Hawkins-Kennedy sign	75.4	44.4	17.0	92.2
Painful arc sign	67.4	47.0	14.9	91.3
Supraspinatus muscle test	32.1	67.8	11.6	88.4
Speed test	33.3	70.6	16.1	88.8
Cross-body adduction test	16.7	78.5	9.9	86.9
Drop-arm test	14.3	77.5	8.0	86.8
Infraspinatus muscle test	19.4	69.1	10.1	87.7
Group 3 (full-thickness rotator cuff tear)				
Neer sign	59.3	47.2	41.3	64.9
Hawkins-Kennedy sign	68.7	48.3	45.2	71.2
Painful arc sign	75.8	61.8	61.0	76.4
Supraspinatus muscle test	52.6	82.4	68.0	71.0
Speed test	39.9	75.3	50.3	66.6
Cross-body adduction test	23.4	80.8	44.6	61.5
Drop-arm test	34.9	87.5	65.0	66.8
Infraspinatus muscle test	50.5	84.0	69.1	70.5

* Explanatory details are provided in Table 2 – 10.

Table 2 - 12: Sensitivity, specificity and confidence interval values in test combinations (taken from[249])*.

Positive tests	*Case number*	*Sensitivity (%)*	*Specificity (%)*	*Accuracy (%)*	*PPV (%)*	*NPV (%)*
All positive	5	4.4	97.2	31.2	80.0	29.1
At least 6 positive	31	30.3	88.8	47.2	87.0	34.0
At least 5 positive	39	38.2	86.1	52.0	87.1	36.0
At least 4 positive	74	69.6	66.6	68.8	83.7	47.0
At least 3 positive	95	84.2	44.4	72.8	78.9	44.4

* Explanatory details are provided in Table 2 – 10.

Table 2 - 13: The likelihood ratios and post-test probabilities for combining clinical tests according to logistic regression analysis results (taken from[276]).

Category	No. (%) of Patients with Positive Test Results		Pretest Probability	Pretest Odds	Likelihood Ratio	Post-Test Odds	Post-Test Probability
	Subject	Control					
Overall impingement syndrome*							
All three tests positive	61/231 (26.4)	3/121 (2.5)	0.65	1.86	10.56	19.64	0.95
Two of three tests positive	86/231 (37.2)	9/121 (7.4)	0.65	1.86	5.03	9.36	0.90
One of three tests positive	60/231 (26.0)	35/121 (28.9)	0.65	1.86	0.90	1.67	0.63
None of three tests positive	24/231 (10.4)	74/121 (61.2)	0.65	1.86	0.17	0.32	0.24
Full-thickness rotator cuff tear†							
All three tests positive	50/153 (32.7)	4/195 (2.1)	0.39	0.64	15.57	9.96	0.91
Two of three tests positive	53/153 (34.6)	19/195 (9.7)	0.39	0.64	3.57	2.28	0.69
One of three tests positive	36/153 (23.5)	58/195 (29.7)	0.39	0.64	0.79	0.51	0.33
None of three tests positive	14/153 (9.2)	114/195 (58.5)	0.39	0.64	0.16	0.10	0.09

*A total of 352 patients (231 in the subject group and 121 in the control group) who underwent all three tests (the Hawkins-Kennedy impingement sign, the painful arc sign, and the infraspinatus muscle test) were included in this analysis. The subject group included patients with bursitis, partial-thickness rotator cuff tear, or full-thickness rotator cuff tear; the control group was the nonimpingement group. †A total of 348 patients (153 in the subject group and 195 in the control group) who underwent all three tests (the painful arc sign, drop-arm sign, and the infraspinatus test) were included in this analysis. The subject group included patients with a full-thickness rotator cuff tear only; the control group included patients without impingement and patients with bursitis or a partial-thickness rotator cuff tear.

2.14 Self-Reporting Upper Extremity Function and Quality of Health

Self-reporting questionnaires, either joint-specific, region-specific or general health outcome measures, are increasingly based on terminology and concepts from the 'International Classification of Functioning, Disability and Health'[277]. Self-reporting questionnaires facilitates the standardized collection of subjective data as experienced by patients themselves; in addition, they may contain objective assessments to be conducted by clinicians. Regarding shoulder problems, there are several validated and reliable questionnaires. The joint-specific scoring systems include the Constant-Murley scores (CMS) and Oxford shoulder score (OSS)258. The upper limb-specific questionnaires contain Disability of Arm, Shoulder and Hand (DASH) score and the upper limb functional index (ULFI). The general physical and mental questionnaires involve general health status SF-12 and hospital anxiety and depression. The pain-specific questionnaire includes McGill pain questionnaire (MPQ). All together provide extensive information on impairments due to pain, limitation in ROM, weakness and to what extent they may interfere with daily living activity, recreation, job and psychosocial integrity.

2.14.1 Constant-Murley Score

The Constant-Murley Score (CMS)[278] has become the most widely used shoulder evaluation instrument in Europe. This scoring system combines physical examination tests with subjective evaluations by the patients. The subjective assessment consists of 35 points and the remaining 65 points are assigned for the physical examination assessment.

The subjective assessment includes a single item for pain (15 points) and 4 items for activities of daily living (work 4, sport 4, sleep 2, and positioning the hand in space 10 points). The objective assessment includes range of motion (forward elevation, 10 points; lateral elevation, 10 points; internal rotation, 10 points; external rotation, 10 points) and power (scoring based on the number of pounds of pull the patient can resist in abduction to a maximum of 25 points). The total possible score is therefore 100 points.

2.14.2 Oxford Shoulder Score

The Oxford Shoulder Score (OSS) is a condition specific questionnaire. It was published in 1996 to deal with patients' perception about shoulder surgery other than stabilization. As a patient-based measure, it was found reliable and internally consistent to assess medium term outcomes (6 months – 4 years) following shoulder surgery for rotator cuff disorders[279,280]. Cloke and colleagues (2005)[281] compared OSS, SPADI and SF-36 for their agreement, sensitivity to clinical change and reliability in 110 patients with SIS. According to their results, they support the use of OSS in patients with SIS.

OSS consists of 12 questions exploring pain (4 questions) and function (8 questions). Each item was originally scored from 1 to 5, from least to most difficulty or severity, and combined to produce a single score with a range from 12 (least difficulties) to 60 (most difficulties)[282]. More recently, changes to the method of scoring have occurred with each question in OSS being scored 0–4, with four representing the best (this is the opposite direction from the original method of scoring). When the 12 items are summed, this produces overall scores from 0 to 48 with 48 being the best outcome (to convert the old system of 60–12 to the 0–48 scoring system and vice versa simply subtract the score from 60)[283]. The internal consistency of this test was measured using Cronbach α, with correlation coefficient of 0.89 at the preoperative assessment and 0.92 at 6-month follow-up. The coefficient of test-retest reliability was calculated as 6.8 using the Bland and Altman method. The validity of this questionnaire was established by obtaining significant correlation with CMS, Short Form (36) (SF-36) and Health Assessment Questionnaire[284].

2.14.3 Disability of Arm, Shoulder and Hand

The Disability of Arm, Shoulder, and Hand (DASH) questionnaire is a standardized questionnaire that assesses the symptoms and functional status in people with different upper extremity musculoskeletal disorders[285]. The questionnaire consists of 3 sections: Symptoms, Sport and Music, and Work. The first section is composed of 30 items and evaluates symptoms and functional status at the level of disability. The second and third sections are an optional module of 4 items for Sport and Music and 4 items for Work. Each item is scored with a 5-point scale: 1 = no difficulty; 2 = mild difficulty; 3 = moderate difficulty; 4 = severe difficulty; 5 = unable. The result of each module is summed and transformed to obtain the DASH score ranging, for each section, from 0 (no disability) to 100 (severe disability). Relatively to internal consistency, the DASH has been shown in multiple tests to have a high Cronbach α (0.97); the questionnaire responsiveness (to self-rated or expected change) was similar to if not better than that of the joint-specific measures in the whole group and in each region[286].

2.14.4 Upper Limb Function Index

The Upper Limb Function Index (ULFI) is a region specific tool developed by Gabel et al. (2006)[287]. The ULFI was introduced to compensate deficits in feasibility, reliability and responsiveness that were observed in other region-specific tools such as DASH, the Upper Extremity Functional Scale; the Upper Extremity Functional Index and the Neck and Upper Limb index[287]. For the purpose of validation, test – retest reliability and responsiveness, Gabel et al. (2006)[287] investigated 214 responses from 139 subjects with upper limb symptoms, and suggested that the ULFI is the preferred region-specific tool with superior practical characteristics and clinical utility, and comparable psychometric properties. The index consists of 25 items which focus on health-related quality of life and upper limb functional impairment. A box is ticked by the subjects if the provided description applies to their condition. The quantitative data has been made by adding the ticked items and multiply the sum by 4 to bring the score to 100%, which indicates the worst outcome. The ULFI has not been reported in patients with SIS, since it was published in 2006.

2.14.5 General Health Survey SF-12

Regression methods were used to select and score 12 items from the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36) to reproduce the Physical Component Summary and Mental Component Summary scales in the general US population (n=2,333). The resulting 12-item short-form (SF-12) achieved multiple R squares of 0.911 and 0.918 in predictions of the SF-36 Physical Component Summary and SF-36 Mental Component Summary scores, respectively. Scoring algorithms from the general population used to score 12-item versions of the two components (Physical Components Summary and Mental Component Summary) achieved R squares of 0.905 with the SF-36 Physical Component Summary and 0.938 with SF-36 Mental Component Summary when cross-validated in the Medical Outcomes Study. Test-retest (2-week) correlations of 0.89 and 0.76

were observed for the 12-item Physical Component Summary and the 12-item Mental Component Summary, respectively, in the general US population (n=232). Twenty cross-sectional and longitudinal tests of empirical validity previously published for the 36-item short-form scales and summary measures were replicated for the 12-item Physical Component Summary and the 12-item Mental Component Summary, including comparisons between patient groups known to differ or to change in terms of the presence and seriousness of physical and mental conditions, acute symptoms, age and ageing, self-reported 1-year changes in health, and recovery for depression. In 14 validity tests involving physical criteria, relative validity estimates for the 12-item Physical Component Summary ranged from 0.43 to 0.93 (median=0.67) in comparison with the best 36-item short-form scale. Relative validity estimates for the 12-item Mental Component Summary in 6 tests involving mental criteria ranged from 0.60 to 107 (median=0.97) in relation to the best 36-item short-form scale. Average scores for the 2 summary measures, and those for most scales in the 8-scale profile based on the 12-item short-form, closely mirrored those for the 36-item short-form, although standard errors were nearly always larger for the 12-item short-form.

2.14.6 Hospital Anxiety and Depression Scale

The hospital anxiety and depression scale (HADS) was developed in 1983 by Zigmond and Santi[288] to emphasize the rule of psychiatric disorders in chronically ill patients and their negative effect on treatment outcomes. Clinicians in non-psychiatric settings have observed manifestations of anxiety and depression in patients with increasing stresses due to chronic pain, functional impairment, and physical disability[289]. Furthermore, the exaggerated symptoms in patients with musculoskeletal disorders without proportional organic pathology and resistance to treatment have been attributed psychosocial factors[290,201].

The scale is limited to the two most common psychiatric domains, anxiety and depression; which are reflected with 7 items on each domain[288]. The validity and reliability of HADS have been demonstrated in chronically ill patients with varying severity of emotional disorders[291-294]. HADS has been reported to be efficient in assessing the symptom severity of anxiety disorders and depression in somatic, psychiatric and primary care patients and in the general population[289]. It has been proposed that the HADS is also useful in patients with chronic musculoskeletal pain[295]. Although no reports has been found on the use of HADS with SIS patients, recently HADS was used to investigate the psychological impact of tennis elbow[290] and massive rotator cuff tear[296].

2.14.7 McGill Pain Questionnaire

Melzack and Torgerson (1971)[297] developed the McGill Pain Questionnaire (MPQ) using the expressions of pain character to assess the sensory, affective, evaluative and miscellaneous dimensions of pain[298], in addition to the intensity of pain. The MPQ is designed to provide a quantitative measure of pain quality. The questionnaire classified 78 words in 20 different groups that represent the four major dimensions of pain quality: sensory, affective, evaluative and miscellaneous. Each of the 78 words is assigned a point, ranging from 1-6 depending on the number of words in each group[299]. The sum of the rank values is the pain rating index (PRI). The pain intensity is defined by 1-5 severity descriptors that constitute the basis for the present pain intensity (PPI). The MPQ has been validated and its reliability was tested by a number of authors and a normative database has also been produced in populations of cancer, low back pain, dental and obstetric patients[300,299].

2.15 Functional Performance Test

The simplicity, safety and feasibility of FIT-HaNSA, which mimics daily living activities of the shoulder and upper limb, have been demonstrated[58]. This standardized test assesses the contribution of upper extremity activity, strength and stability to optimal shoulder function. Given the key role of muscles in establishing shoulder stability, mobility, and function, it is not surprising that the strength of specific muscle groups is typically viewed as a key outcome measure when evaluating shoulder conditions. Quantitative measures of isometric and isokinetic strength [240,241,144,239,301] and ROM[302,303] have been reported in several studies to dictate the functionality of the shoulder complex. Therefore, in addition to a good ROM, shoulder functionality requires coordinated, muscle activity that maintains sufficient proximal control and allows a wide arc of pain-free movement for completion of tasks of daily life. Thus, it is expected that isolated physical impairments like muscle strength or ROM deficits have demonstrated small to moderate correlation to function. However, this suggests that better understanding of function requires specific functional tests.

The shelving system described by MacDermid et al. (2004)[240] for assessing upper extremity tasks in different levels of required ROM and with a weight of 1 kg, is a feasible, reliable and reproducible functional test in normal individuals as well as most of the patients with shoulder disorders particularly SIS. The limitations for this test are the deficits in ROM and severe pain, particularly at the range of 70-90° of forward flexion and abduction. The reliability and constructed validity was tested on a wide spectrum of patients included severe impingement (patients showed gross limitation in task 2) and mild-moderate impingement (still task 2 was challenging)[240].

The use of FIT-HaNSA and EMG on healthy volunteers and patients with SIS is a first attempt to study the activation pattern of muscles that control the STA and GHJ during simulated daily living activities. Furthermore, the combination of both tools allows the interpretation of the alterations in muscle coordination and timing during forward arm reaching between different levels.

2.16 Prognosis

Poor recovery from shoulder pain is associated with increasing age, severe symptoms, or recurrent symptoms at presentation, and a restricted range of passive abduction with concomitant neck pain[37,159,176,304]. In contrast, mild trauma or overuse occurring before the onset of pain, early presentation, and acute onset are associated with a favourable prognosis. Individual psychosocial factors, such as a passive coping style, fear of movement, and general psychological distress, may play a part in the transition from acute to chronic pain. However, the empirical evidence for the role of these factors comes from studies on low back pain and neck pain[305]. Few studies have examined the effect of work related factors on recovery. Ekberg and Wildhagen (1996)[306] showed that whether a person took long term sick leave depended more on the work situation than on characteristics of the patient.

Recently, evidence based guidelines, developed by occupational health physicians, for managing workers with low back pain have been issued in the Netherlands and the United Kingdom[307]. Some of the recommendations may also apply to shoulder pain that develops in occupational settings. This would imply that efforts to prevent and treat shoulder pain should be directed at both physical and psychosocial factors, and initiatives should engage both employers and workers in attempts to identify and control risk factors and implement optimal programmes to enable employees to return to work. People with shoulder pain should remain active and return to normal activity or temporarily modified work as soon as possible. In a later stage of the disease a strategy for returning to work that integrates modified work, functional restoration, and cognitive a strategy for returning to work that integrates modified work, functional restoration, and cognitive behavioural treatment may be appropriate.

2.17 Prevention

Attention should be paid to avoid pain during daily activities and at work. The extreme position of the shoulder for substantial amount of time may induce pain, therefore, extreme movements when the arm extended behind the back, adducted or outward rotated should be avoided[307]. Activities with repetitive movements of the shoulder should avoid force and allow sufficient time for recovery. Overhead reaching should be allowed for short periods and should not include heavy loads. Furthermore, vibrating tools should not be used for a prolonged time[159]. Work tasks should be varied, with enough time allocated to do them, and employees should be offered opportunities for developing their jobs and influencing their work patterns[165]. Routine shoulder exercises are helpful to maintain wide range of movements in all directions as well as prevent stiffness and pain. In secondary prevention there have been some promising results from a cognitive behavioural therapy approach, which implies that addressing these factors may also reduce shoulder pain[232].

Evidence for the risk factors and prognostic indicators of shoulder pain should be studied longitudinally. Without data on the importance of each risk factor and the dose-response relation it is difficult to design effective preventive measures. Before implementation, the cost effectiveness of these interventions should be carefully evaluated[165].

2.18 Treatment

Current evidence fails to show differences in effectiveness between non-operative and surgical treatment of SIS [308]. Most patients with shoulder impingement eventually recover with non-operative intervention [70]. The most common non-operative modalities include modification of activity, the use of non-steroidal anti-inflammatory medications, subacromial injections of steroids, and physiotherapy programmes.

In a retrospective review study of 616 patients (636 shoulders) who had SIS, Morrison et al. (1997)[309] assessed the results of non-operative treatment. Overall, 67% had a satisfactory result with non-operative treatment, of whom 18% showed later recurrence of symptoms; and 28% required arthroscopic subacromial decompression. A small group (5%) had an unsatisfactory result but declined additional treatment. In a systematic review of interventions on painful shoulders, Green et al. (1998)[310] found no evidence to support or rule out the efficacy of common interventions for shoulder pain.

Only in 2 of 8 trials, Koester et al. (2005)[311] showed clinically relevant improvements in pain and range of motion in the injection groups as compared with placebo. However, in both of these studies the outcomes of patients treated with injection and oral NSAIDs were equivocal. Kromer et al. (2010)[312] compared the effectiveness of individualized physiotherapy to standard exercises protocol. The individualized physiotherapy programme is based on an individual's own pain, any specific limitation in function, a defined decision making process; and finally, how to overcome the influence of fear of movement on the outcome of patients with SIS.

2.19 Electromyography

2.19.1 Definition and Concept

Electromyography (EMG) is an experimental and diagnostic technique concerned with identifying, recording and analysing the myoelectric signals which are generated by physiological variations in the state of muscle fibre membranes[111]. Since the time when studies as Hirschberg and Dacso (1953)[313] were published, the clinical use of EMG with dynamic loaded activities led to recognising the importance of inferring information from myoelectric signals to muscle function and shoulder kinematics which imposed the necessity of associating EMG data with clinical kinesiology.

2.19.2 Physiology underlying Electromyography Signal Development

Muscle fibres have to be stimulated to initiate contraction. Each fibre of a muscle receives its innervation by one single motor neuron via an axon. A motor neuron and its associated fibres form one motor unit (MU). One motor neuron may control between three and 2000 muscle fibres depending on the required fineness of control[314].

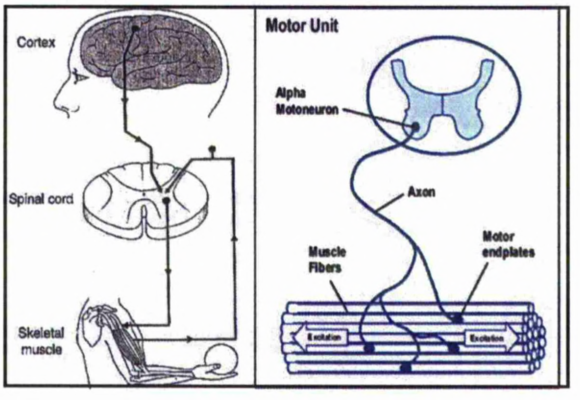


Figure 2 - 8: Central control and motor unit

The axon branches out and connects to individual motor end plates which are usually found in the middle of a muscle fibre. The transmitted motor unit action potentials (MUAPs) to related muscle fibres produce electrochemical changes at the motor end plates, changes in the permeability of and ionic movements across muscle cell membrane. These changes lead to a depolarization-repolarisation cycle, bidirectional propagation of depolarisation waves and spreading of the action potential along the length of the muscle fibre. Because of the conductivity of the tissues around the muscles, a bipolar electrode, placed on the skin over an active muscle, picks up the difference between generated action potentials in the underlying muscle membrane as myoelectric signals. When an action potential is generated at (T1) and propagates along the muscle fibre towards to (T5), the potential difference between the two electrodes is maximally positive at (T2) and maximally negative at (T4) [Figure 2 - 9]. Although simplified to a single muscle fibre, this model illustrates the generation of a bipolar signal from the action potential that propagates along the surface of an activated muscle fibre (Noraxon). As several muscle fibres belong to a single motor unit, they are activated together. Therefore, the final signals detected by the electrodes represent the summations of MUAPs generated in stimulated muscle fibres [Figure 2 - 10].

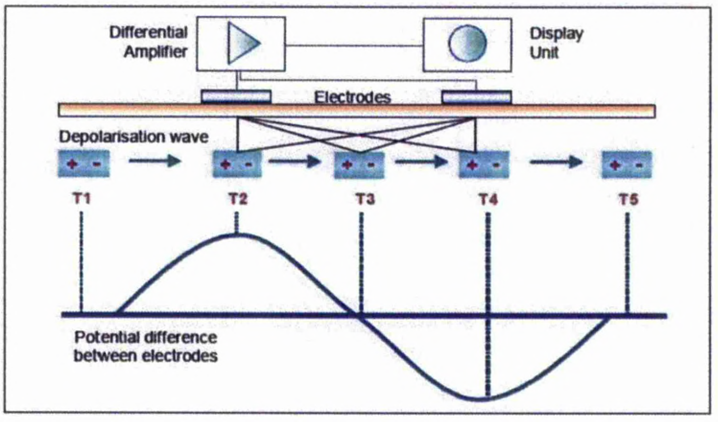


Figure 2 - 9: Generation of a bipolar EMG signal as a consequence of an action potential propagating along a muscle fibre (from ABC of EMG)

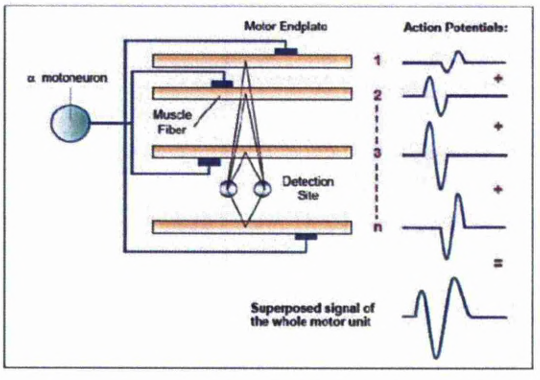


Figure 2 - 10: A motor unit action potential

Schematic representation of the motor unit action potential formed by summation of the polarisation waved of each individual muscle fibre. (from the ABC of EMG- Noraxon)

When the motor unit is repetitively stimulated, it gives rise to a number of MUAPs known as an action potential train (MUAPT)[111]. Finally, the so called 'interference pattern (IP)' which is an algebraic summation of a frequency-modulated MUAPT from a number of activated motor units during a given muscle contraction represents the final raw EMG signals[111,315-317].

2.19.3 Factors Influencing Interference Patterns

Table 2 - 14: A summary of the factors affecting interference patterns

Factor	Variables describing the EMG IP	Studies
Age	Weak differences between 20 and 65 years.	Hayward (1977)[318]
	Significant difference outside the above age-range	Stalberg et al. (1983)[319]
	RMS and MPF were smaller in elderly subjects (above 65)	Akataki et al. (2002)[320]
Sex	No difference with 30% MVC	Christensen et al (1986)[321]
	Endurance decrease for trunk-holding test (120s.)	Umezu et al. (1998)[322]
	MUAP duration, rise time and number of turns	Cioni et al. (1994)[323]
Force	Amplitude increases with increasing force	Sanders & Paoli (1996)[316]
	Recruitment of larger MUs, territory and muscle fibre diameter	
	The number of spikes increases with force at low level of MVC	
Muscle	The AIPEA seems to increase with increasing muscle mass	Sanders & Paoli (1996)[316]
	MUAP wave-forms are considerably different between muscles as well as the fibre types	
Fatigue	Sustained isometric MVC decreases zero-crossings, spikes and T/S ratio.	Hagg (1992)[324]
	Sustained submaximal isometric voluntary contraction, the number of number of spikes and T/S decrease, while amplitude increases	Finsterer & Mamoli (1996)[325]
Fitness	The reduced integrated IP activity in immobilized legs or functional disuse was attributed to functional loss of motor units	Fuglsang-Frederiksen (1978)[326] Fuglsang-Frederiksen (2002)[327]
Recording site and surrounding tissue	No differences when surface electrodes placed between the endplate zone and sites near the tendon (e.g. BB).	Finsterer (2001)[12]
	Tissue filter effect is reduced with increased force from 20-50% MVC as more MUs near the surface of the muscle are recruited	
Electrodes	No change in power spectra with the use of bipolar or monopolar surface electrodes.	Cioni et al. (1994)[323]
	Power frequency and T/S showed significant changes when recordings from surface and concentric electrodes were compared	Preece et al. (1994)[328] Finsterer et al. (2003)[329]
Sensitivity	A sensitivity of 1-2 mV should not be exceeded when needle electrodes are used	Finsterer et al. (1993)[330]
Filters	Elevation of the lower limiting frequency leads to loss of small MUs contribution, and lowering the upper limiting frequency leads to miss the contribution of large MUs	Finsterer (2001)[12]
Sampling frequency	At MVC of the deltoid muscle, mean power frequency, but not RMS, increased linearly with increasing sampling frequency from 4-10 kHz	Sadhukhan et al. (1994)[331]
	Sampling frequencies >50 kHz are required in certain conditions	Jorgensen et al. (1991)[332]
Threshold level	Traditionally, the value of 100 μV is selected as amplitude threshold. Lowering the threshold to 50 or 25 μV increases the sensitivity to detect neuro-myopathic disorders.	Willison (1964)[333]
Pain	Overall, the diagnostic yield of IPA is limited in cases with chronic tension or pain	Fuglsang-Frederiksen (2000)[327] Qerama et al. (2005)[334]

* T/S: turn/second A/T: Amplitude/Turn

2.19.4 Determinants of Interference Pattern

There are several determinants of IP appear in Table 2-1. The amplitude measurements and power spectrum analysis (PSA) will be described as they are relevant for this study.

2.19.4.1 Amplitude Measurements

The amplitude is defined as the time-varying deviation of the electrical signals[335].

The mean amplitude, the root mean square (RMS) and the peak amplitude are used usually with muscle activation. The filtered, rectified and smoothed raw signals are summarized as the moving average or mean amplitude. The peak amplitude is referred as an index of maximal muscle activity when the electrical activity is relatively constant. RMS amplitude is calculated as the square of individual amplitudes averaged, followed by calculation of the root. The RMS is quantifying the effective value of EMG signal in mV. It is used to measure electrical power, firing rates, duration and velocity[336,314,327].

Table 2 - 15: Variables describing the electromyography interference pattern[12]

Variable	Dimension
Subjective density	none
Subjective amplitude of the IP envelope (AIPES)	mV
Zero-crossings	Hz
Spikes	Hz
Amplitude variables	µV
Integrated activity	µV*ms
Firing frequency	Hz
MUAP variables	various
Spectral frequency	Hz
Power	dB
T/S	Hz
A/T	µV
T/S:A/T	Hz*µV
UCA	µV
NSS	n
Activity	ms
Automatic amplitude of the IP envelope (AIPEA)	mV

2.19.4.2 Power Spectrum Analysis

Fast Fourier transformation (FFT) is used to decompose IP into sinusoidal-waves of different phases, frequency and amplitude of the power spectrum[321,337]. The total power spectrum of the surface EMG signal is represented by the area outlined by the curve of power spectrum [Figure 2 – 11][324]. The frequently evaluated descriptors are the mean frequency (MnF) and the median frequency (MdF) which are computed easily using current algorithms and used as parameters of muscle fatigue (Noraxon). The MdF divides the power spectrum into low and high frequency ranges that both contain the same power. Other useful parameters are the peak frequency (frequency with the maximum power), total power (sum of individual power values) [Figure 2 – 12], relative power frequency at a certain frequency, and ratio of high to low frequency values[338].

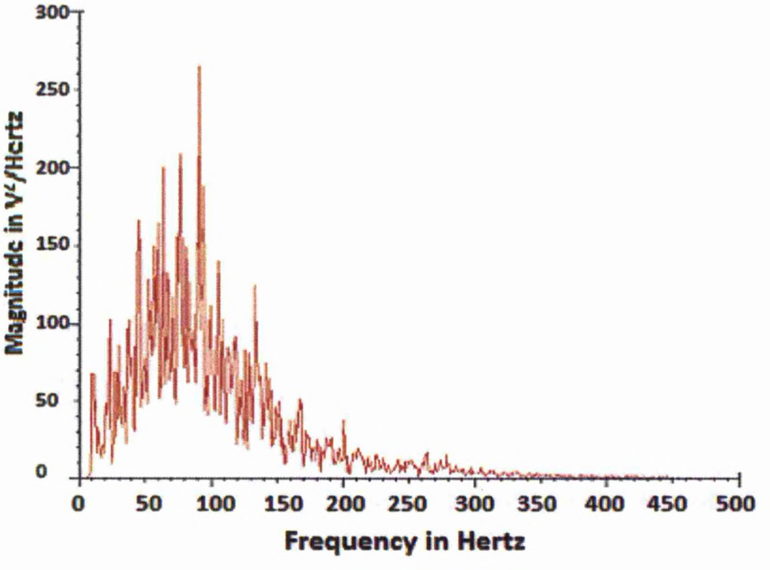


Figure 2 - 11: The total power spectrum of a surface EMG recording

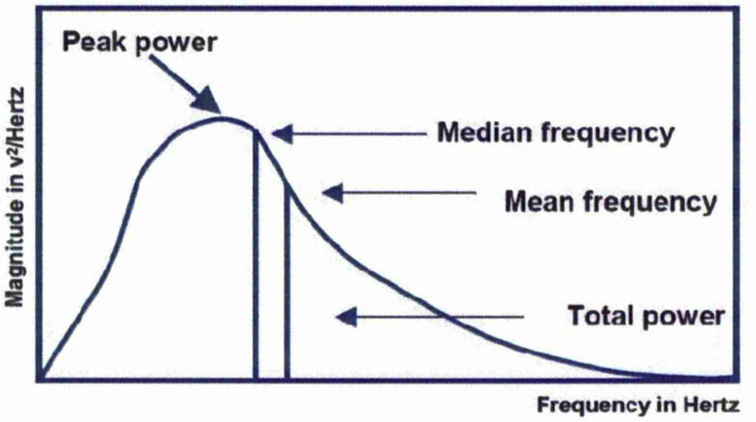


Figure 2 - 12: Frequency parameters of the power spectrum (from the ABC of EMG Noraxon)

To show the distribution of power and frequency over a wide range, it is customary to use logarithmic scales along the frequency (x-axis) and power axis (y-axis). The major frequency band of the power spectrum results from MUAP-duration[316]. High frequencies reflect MUAPs with short rise-time, short duration, and polyphasic wave-form. Low frequencies reflect long duration MUAPs with long rise-time.

FFT analysis can be performed on successive epochs over the duration of the contraction, yielding the temporal trend in the mean or median frequency. Merletti proposes that epochs of 1 second duration be chosen. Shorter epochs will result in higher variance of the estimates of spectral variables[339] and longer epochs will violate the hypothesis that signals are stationary[340]. The configuration of the total power spectrum can vary widely, depending on the FFT-settings, muscle properties such as fibre type length and tissue/skin filter effects.

The checking features of the prower spectrum include: (1) steep increase from the high pass (10Hz), (2) the peak frequency typically located between 50 and 80 Hz, (3) the spectrum curves decreases and reaches zero between 200 and 250 Hz, (4) checking if untypical power peaks are visible, especially outside the band-range, (5) checking if a dominant power peak is visible at 50 (EU) or 60 (USA) Hz (Noraxon). In the majority of the cases, PSA is applied to IPs recorded with surface electrodes[341,338,342]. IPs recorded with needle electrodes infrequently undergo PSA[343,344].

2.19.5 Signal Processing

The raw EMG signals are arbitrary in nature and without sustained repeatability. This random nature is based on the variability in location, number and size of the firing motor units. The raw EMG signals are very valuable for qualitative analysis of the muscle activation pattern. Once quantitative measures are required, the raw signals need to be specifically processed. The signal processing includes full wave rectification, smoothing and normalisation[345,111,346].

2.19.5.1 Initial Check

The zero-line-correction should be maintained, followed by removing electro-cardiogram (ECG) artefacts and then filtering. Regarding surface EMG, finite impulse response (FIR) filtering is commonly used with a band-pass of 10 Hz low frequency and 500 Hz high frequency. In case of fine wire (FW) EMG, infinite impulse response (IIR) filter with high-pass frequency of 10 Hz and Butterworth approximation is applicable (Noraxon). The advantage of high pass filtering is the removing of movement artefacts, particularly in dynamic measurements. Basmajian and De Luca[111] recommended 20 Hz as a corner frequency of the high pass filter for surface detected EMG signal in order to avoid the lower frequency of motion artefacts[111]. A lower frequency cut-off (10 Hz) for EMG spectral analysis is, however, adapted by the fact that in, some cases, necessary information of active MUs come within this frequency range[347].

2.19.5.2 Rectification

The raw EMG signals which are initially distributed on both sides of the zero-line are totally turned into positive values starting from the zero-line upwards [346]. This step allows quantifying the signals in amplitude and peak EMG. The area under the rectified EMG, the so called integrated EMG (IEMG), as well as the equivalent mean EMG related to a time sector, results in the first detailed information about muscular activity[111].

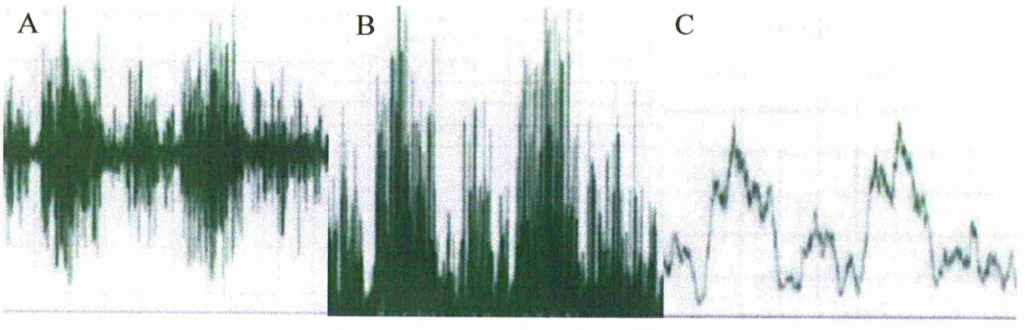


Figure 2 - 13: Signal processing (A) Raw signals, (B) Full wave rectification, and (C) Smoothing (RMS window 100ms)

2.19.5.3 Smoothing

The rectified EMG is performed by one of two mathematical algorithms. Smoothing is achieved either with the commonly used RMS or with moving average. The EMG signals obtain a more precise envelope and activity pattern.

2.19.5.4 Electromyography Signal Amplitude Normalization

Amplitude normalization procedures are used when recording EMG signals because there is a necessity to reduce inherent physiological variability between individuals, and technical variability associated with electrode replacement [348]. Individual data are commonly amplitude normalized before calculating group means, and expressed as a percentage of a reference value. The coefficient of variation (CV), which expresses the ratio of the standard deviation as a percentage of the mean, is often used to compare transformed data. The effectiveness of an amplitude normalization technique has been based on its ability to reduce the CV of the processed data when compared to the raw data.

2.19.5.4.1 Methods of Amplitude Normalization

There are two methods for the normalization of amplitude include: (1) Amplitude normalization to a signal recorded in MVC test: The use of MVC to normalize raw EMG signals provides a direct indication of the level of activity of each muscle[128] and is commonly used method of normalization. The problem with this method of normalisation is the effect of pain, training and motivation on performing MVC[349]. Pain will reduce the generation of muscle force. Training and verbal encouragement of subjects has been demonstrated to improve MVC by 30%[350]. Furthermore, the appropriateness of utilising an isometric contraction to normalise EMG data obtained during dynamic tasks has been questioned[349]. Indeed, Burden suggests EMG from an isometric MVC may not represent the maximum activation of the muscle at lengths other than those at which the MVC was performed[351]. (2) Amplitude normalization to the mean: In protocols with dynamic movements, the amplitude is normalized to the mean of the cycle motion[352,353]. Although the mean amplitude normalisation does not provide information on the absolute degree of activation, they provide information on the patterns of muscle activity[353], which can facilitate a comparison between study groups.

2.19.5.5 Time Normalization

To provide comparative information between activated muscles or to investigate subjects during a cyclic motion, the exact duration of each cycle will not be consistent, therefore, normalisation in the time domain is important to compare phases in cycles and both between different muscles and individuals. Allison, Marshall and Singer reported the effect of 11 amplitude normalization techniques on the coefficient of variation (CV) during the eccentric and concentric phases of stretch-shortening cycles (SSC) [354].

2.19.6 Types of Muscle Contraction

The EMG patterns may differ depending on which type of contraction:

2.19.6.1 Muscle Contraction with Joint Movement (Isotonic Contraction/Dynamic Contraction)

The contraction of a muscle with movement against a natural resistance is known as 'isotonic contraction', meaning 'same tension', which is not the case with a muscle that changes in length and natural biomechanics that produce a dynamic resistance curve. This misnomer has prompted authors to propose alternative terms, such as dynamic tension or dynamic contraction.

There are two types of the isotonic/dynamic contraction: (1) Concentric contractions are those that cause the muscle to shorten as it contracts. (2) Eccentric contractions occur when the muscle lengthens (stretches) as it contracts. Forward elevation of the shoulder reveals increased muscle activity of the AD as it contracts concentrically as well as increased muscle activity in the ISP and LD as they contract eccentrically in order to avoid superior translation of humeral head during arm elevation. During lowering of the arm, the ISP and LD act concentrically while the AD acts eccentrically.

Active movements of the shoulder may alter the EMG signals following a change in the distance between the stimulated muscle fibres and overlying electrodes, in addition to a change in the length-tension property of the muscle fibre to generate force[111]. Using EMG Kronberg et al. (1995)[355] compared muscle activity during eccentric movements with previously studied concentric movements and concluded that the magnitude of activation was significantly lower during eccentric muscle contraction. Ebaugh et al. (2010)[116] demonstrated that scapulothoracic muscles (UT, LT and SA) had less muscle activity levels during eccentric contractions.

2.19.6.2 Isometric Contraction – No Joint Movement

A constant muscle fibre length is maintained during isometric contractions; a balance is preserved between exerted force and resistance, therefore, there is no change in muscle length. A position of maximal activity of a single muscle or a group of muscles during resisted isometric contraction is a prerequisite for EMG assessment of the MVC amplitude. A high correlation between the EMG amplitude estimate of the muscle activity and the force generated by the same muscle is expected from physiological considerations[111,356]. In contrast, this myoelectric signal-force relationship can vary in different muscles. For example, Lawrence et al. found a linear amplitude to force correlation in the first dorsal interosseous but non-linear correlation in the deltoid and BB muscles[357].

The type of recruited MUs and the rate of discharge by those MUs are determining factors on the existing variability on the force that a muscle exerts. The morphological alterations in the innervations ratio, muscle fibre type distribution and average cross-sectional area of MUs lead to inconsistency in the maximal MU force and may vary by approximately 50 times[358]. In addition to the MU morphological variability, cross talk from neighbouring muscles, agonist and antagonist co-activation and viscoelastic properties contribute in the myoelectric signal-force relationship[357].

2.19.7 Shoulder Muscle Activation Pattern

2.19.7.1 Muscle Activation Pattern in Healthy Shoulders

EMG studies on human muscles have added much by investigating various phases of arm elevation and lowering in different planes. Recognised roles of muscles have changed and unsuspected muscles have been shown to take active part in different phases of shoulder motion.

The shoulder girdle motion is effective with the integrity of sternoclavicular joint, acromioclavicular joint and STA. The Axio-scapular muscles (LS, UT, MT, LT, SA and RM) control the shoulder girdle motion and allow the scapula to act as a platform. This stable platform facilitates the development of accurate length-tension property of the muscles crossing the GHJ and the generation of controlled forces that move the head of humerus on the glenoid concentrically in a wide range of motion. In normal conditions, all the joints of the shoulder complex act in a consistent and co-ordinated way to perform several non-compromised motor functions during daily living activities, work and sports. The co-ordination is evident from simultaneous muscle activity in muscles producing the movement and those on the opposite side of the specific motion axis and together provides movement and stability of the shoulder [183,359].

Table 2 - 16: Shoulder muscles control the shoulder complex motion (modified from [117])

Joint involved	Type of movement	Muscle power derived from
1. Sternoclavicular joint	Elevation 30-36°	1. LS 2. UT 3. SA (Upper fibres)
	Rotation 30-40°	1. Force-couple acting on scapula in terminal phase III is transmitted through taut conoid and trapezoid ligaments. 2. Subclavius
2. Acromioclavicular joint	Rotation of scapula round vertical axis through the joint by 20°	1. SA (Upper digits) 2. Pectoralis minor
3. Scapulothoracic joint	Rotation through anteroposterior axis (upward/downward rotation)	1. Upper component of the force-couple derived from LS, UT, and SA (upper digits) 2. Lower component of the force-couple derived from trapezius (middle and lower), and SA (5th - 8th digits) Their action is complementary to produce the desired rotation.
	Rotation through vertical axis (external/internal rotation)	1. SA (prime mover) 2. RM, UT, LT and LS (stabilizers) Their action is complementary to produce the desired rotation.
	Rotation through medio-lateral axis (posterior/anterior tilt)	1. SA (lower digits) 2. UT
1. Glenohumeral joint (GHJ)	Forward elevation and lowering / Extension Abduction/ Adduction Internal / external rotation	1. Largest cone: a. Deltoid (AD, MD and PD b. Triceps and biceps (BB) (long head) c. Coracobrachialis 2. Intermediate cone: a. TM b. PM c. LD 3. Shortest cone: a. SSP b. ISP c. Teres minor d. SUBS

The understanding of EMG recordings and their relation to kinematic patterns of the shoulder complex during standardised movements and dynamic contractions in healthy subjects can be used as reference data when assessing patients with shoulder pathology[123,127]. Minimal alterations in performance and coordination of these muscles have the potential to lead to dysfunctions and compensations that could compromise joint function and lead to disabilities resulting in inactivity and a lower quality of life.

The practitioner should assess whether a muscle recruits at the right time or whether it comes on early or late; whether, once it is recruited, its duration is appropriate for the task; whether the work period is too long or too short; whether the muscle gets a chance to rest between repetitions; whether those rest periods occur often enough; and whether they are long enough. A number of studies have documented shoulder muscle activity in healthy volunteers. Since Inman, EMG still provides further support to the force couple concept and applicable in scapulothoracic and scapulohumeral muscle activity to control kinematics of the STA and GHJ[4,111,360].

2.19.7.1.1Control of the Scapular Position during Arm Elevation

The UT, LT and SA are believed to play an important role in the STA control [121,123,4]. These muscles control upward rotation, external rotation and posterior tilt of the scapula during active arm elevation[123,361]. The passive elevation of the arm is associated with a significant decrease in scapular upward rotation particularly at mid-range[118,362] but no difference with external rotation and posterior tilt.

The UT, LS, and upper digitations of the SA constitute a unit that shares in passive support of the shoulder, allows active elevation of the shoulder, and acts as the upper component of the force couple necessary for scapular upward rotation. The LT and the lower four digitations of the SA constitute the lower component of the scapular rotatory force couple, and are found to act throughout elevation of the extremity in a complementary manner. While LT acts predominantly in abduction, the lower four digitations of SA activate predominantly in flexion[4]. Similarly, RM, LS, and upper digitations of SA form an upper, and PM/Pm, together with LD, a lower component of a force couple producing downward rotation of the scapula[92].

Scapular upward rotation is produced by the UT and lower SA acting as a force couple during the initial phase of arm elevation[121,73,363]. In the middle phase of GH elevation, the LT increases its contribution to control rotation and resists excessive elevation of the scapula[121]. In the final phase of GHJ elevation the UT, LT and lower SA are approximately equally active[121]. Increased activity in SA is associated with lower levels of activation in RM and LS as a synergistic control to possible lateral translation of the scapula. During the reversal of movement of the arm, the upward rotators still show some activity to resist excessive downward rotation and lowering of the scapula[2]. Taylor argued that the LT is the major stabilizer during scapular movement and the relative balance between the UT and LT is maintained when UT/LT ratio is less than 1.0[364].

The EMG activity of the UT and inferior part of SA was investigated in 25 volunteers of both sexes by Bull et al. (1990) during free movements of abduction, flexion, adduction and extension of the arm. They emphasized a synergistic effect of the UT and lower part of SA with increased activity to rotate the scapula upward and externally in abduction; and upward and internally in flexion. Activity in both muscles decreased gradually in adduction and extension to control the return of the scapula to its initial position[365].

Elevation of the arm above 70-90° demands further clearance in subacromial space. The middle and lower SA are aligned with a substantial mechanical advantage not only for scapular upward rotation but also a combined ability to tilt backward and externally rotate the scapula. This position of the scapula provides sufficient room for further elevation of the arm[2]. The risks of inefficient upward rotation, external rotation and posterior tilt of the scapula [Figure 2 - 14] in the development of SIS are reduced when the normal scapular kinematics sustained by optimal function and coordination of trapezius, SA and other muscles attached to the scapula[366].

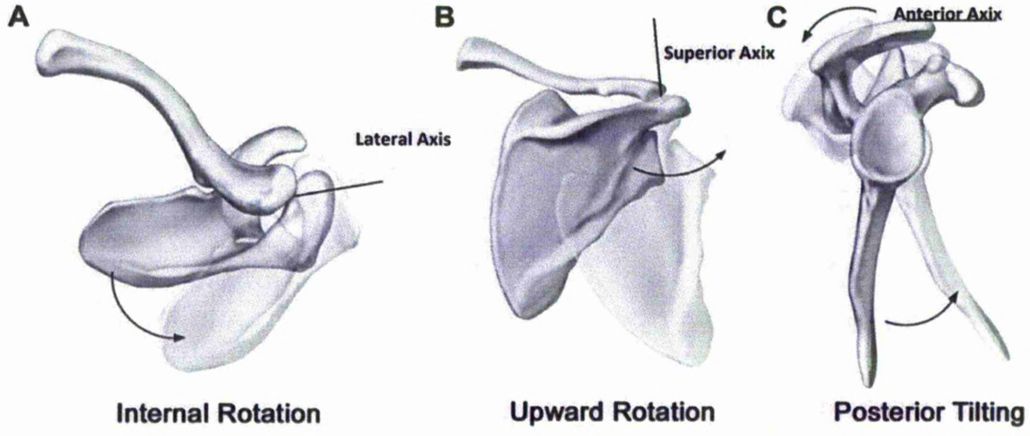


Figure 2 - 14: Scapular rotations relative to the clavicle or thorax.

The scapular rotations include internal/external rotation about a superiorly directed axis (A), upward/downward rotation about an axis perpendicular to the plane of the scapula directed anteriorly (B), and anterior/posterior tilting about a laterally directed axis (C). Adapted from Ludewig et al. (2009)[367].

2.19.7.1.2 Control of Glenohumeral Joint during Arm Elevation

The coordination of scapular movement with that of the humerus (SHR) is a key factor in the functional stability of the GHJ during the daily living activities. The length-tension relationship and load of the rotator cuff and other muscle crossing the GHJ are believed to be influenced by normal kinematics of the shoulder components[19,368,369].

Inman et al. (1944)[4] for example conducted a widely accepted surface EMG study that was able to measure muscle activity associated with movements of the shoulder. They described the importance of force coupling between the deltoid and rotator cuff, noting their synergistic actions during arm abduction. The shear forces across the joint resulting from the upward pull of the deltoids are balanced by the synchronous firing of the cuff, allowing efficient elevation of the arm[4]. Inman et al (1944)[4] concluded that the SSP acts together with the deltoid as a single unit throughout abduction and forward flexion, while the SUBS, ISP and Tm act as a functional unit to depress the humerus continuously throughout abduction and flexion. However, Reddy et al. argued that after the initial phase of elevation of approximately the first 30–60 °, the rotatory contribution of the SSP declines significantly[10]. This may be due to a change in the length–tension relationship and a decrease in the moment arm of the SSP with increased elevation[10,370].

Halder et al. (2001)[371] and colleagues showed that the LD and TM, and to a lesser degree the rotator cuff musculature of the ISP and the SUBS impart an inferior translatory force to the head of the humerus to maintain the congruity of the humeral head with the glenoid fossa. This is critically important for the production of smooth and coordinated glenohumeral movements. From a clinical point of view, quantified EMG recordings from normal shoulder muscles during dynamic upper limb motion similar to daily living activities are of interest as a reference database when assessing patients with shoulder impingement. Subsequently, Kronberg et al. (1990)[127] in 5 subjects, Alpert et al. (2000)[126] in 16 subjects, David et al. (2000)[372] in 15 subjects studied muscle activation during all or part of shoulder standard movements including flexion, abduction, extension, internal and external rotation.

Kronberg et al. (1990)[127], in a study of bilateral shoulders in 5 healthy volunteers described the behaviour of the deltoid and rotator cuff muscles during abduction, flexion, extension and external and internal rotation. During abduction, the AD, MD, SSP and ISP were the most active muscles, followed by the SUBS and LD. During external rotation the ISP and, to a lesser extent, the SSP were the most active muscles. The SUBS, PM and the LD were the most active muscles during internal rotation. During flexion, the AD and MD and the ISP and the SSP were the most active muscles whereas the PD, MD, SUBS and SSP were the most active muscles during extension.

Alpert et al. (2000)[126] conducted EMG analysis on the deltoid and rotator cuff in 16 healthy volunteers to investigate varying loads and speed effects. Changes in EMG activity were observed with loading and increased speed in different ranges of scaption. With additional load to the arm EMG activity increased during the first 90° of motion and lowered during the final 30° of motion. Doubling the speed caused an increase in EMG activity during the first 60° of motion and a decrease in activity in the final 60°.

David et al. (2000)[372] identified the muscle activation patterns of 8 shoulder muscles including the deltoid 3 components, the rotator cuff components except teres minor, long head of BB and PM; in 15 healthy volunteers and during isokinetic internal external rotation. The findings indicated that for both types of rotations, the rotator cuff and biceps were active prior to the initiation of the actual movement and prior to onset of deltoid and PM activity. They related those patterns to normal recruitment of the rotator cuff and biceps as a non-specific presetting phase prior to actual rotation of the shoulder joint. Once movement is in progress, the EMG patterns of these muscles become movement specific[372]. There have been studies of muscle activity in more complex situations such as conical shoulder motion [373], and eccentric tasks[355]. However, these are only a small part of the range of motion over which the shoulder functions.

Very recently, Hawkes et al. (2012)[374] used EMG recordings during FIT-HaNSA, which simulates daily living activities of forward reaching, elevation and lowering, and overhead activity[58]. The activation pattern was reported on 12 shoulder muscles in 12 healthy male volunteers. Highly significant positive correlations between the deltoid and rotator cuff, the deltoid and adductor and the adductor and rotator cuff groups were found[374].

2.19.7.2 Muscle Activation Pattern in Shoulders Affected with Subacromial Impingement Syndrome

An important common element in patients with chronic pain is the abnormal activation of the muscles as a response to pain. The muscle activation pattern is often presented as an element in a complex vicious circle that represents the process of changing abilities, behaviour and personal properties. As a response to pain, subjects do alter their muscle activation in such a way that it will contribute to an avoidance of more pain, i.e. they avoid the movements that cause pain. This response can work out in different ways with respect to the muscle activation: one can avoid activating the muscles or one can stiffen the joints by activating the surrounding muscles rather constantly. It will be clear that in both responses an abnormal muscle activation pattern will become apparent [375].

Chester et al. (2010)[48] reviewed 11 papers from 9 studies with high scores of eligibility criteria based on the Critical Appraisal Skills Program (CASP) tool for observational studies, recommended by the Public Health Resources Unit of the NHS (Critical appraisal skills programme, 2006). The studies were conducted on 141 patients with SIS and compared to 138 healthy volunteers. The sample size ranged from18-69 subjects and the age range was between 16 and 66 years old. All studies were comparative observational/case-control designs. Table 2 - 17 included the authors of the studies, procedures and relevant EMG analysis; and Table 2 - 18 illustrated the findings in muscle activation level and onset in selected shoulder muscles.

Table 2 - 17: Details of task procedures and EMG analysis in 11 publications from 9 studies comparing EMG variables between patients with SIS and controls[48]

Paper	Task (test procedures and functional movement)	EMG variables analysed
Bandholm et al, (2006)[47]	In Kin-Com, elbow flexion 90°. Isometric MVC shoulder scaption 90° in int/ ext/zero rotn at 20, 27.5 and 35%MVC. Isokinetic Abduction recorded concentrically 40-45° and 95-100°, eccentrically at 110-95° and 55-40°	Average normalised EMG amplitude during: (i) Isometric contractions (9 s) (ii) Concentric and eccentric isokinetic contractions during 40-55° and 95-110° abduction in scapular plane
Brox et al (1997)[376]	Maximum voluntary isometric contraction (MVIC) and subMVIC at 45° isometric scaption, in 90° elbow F.	Average EMG amplitude (normalised and non-normalised) during: (1) sustained 25% submaximal MVIC until exhaustion. (2) MVICs (3 s) at 30 s, 3 min and 20 min post-exhaustion
Clisby et al (2008)[377]	Resisted isometric external rotation at 10%, 40% and 70% MVC with and without shoulder adduction.	Average normalised EMG amplitude during the middle 5 s of the different contraction levels.
Cools et al (2003)[182] (Onset times)	Seated in Biodex isokinetic dynamometer. Action: to resist an unexpected drop (release of lever arm from locked position) when shoulder in 90° abduction.	EMG onset times determined as point at which signal exceeded 10% of MVIC amplitude. Latencies (muscle response times in test) calculated.
Cools et al (2007)[378]	Seated on Biodex, isokinetic dynamometer Sitting, trunk fixation.(1) Isokinetic abduction/ abduction in frontal plane 120°/s, (2) external rotation in 45°scaption (30° anterior to coronal plane) 60°/s.	Average normalised EMG amplitude of the 5 repetitions of each activity.
Finley et al (2005)[379]	Wheelchair transfers from chair to bed from dominant and non-dominant sides.	Normalised peak EMG amplitude during phases of transfer (each 30° of humeral elevation).
Ludewig and Cook (2000)[19]	Standing, unilateral scaption with and without a 5 or 10 lb (2.3/4.6 kg) load. One cycle every 4 seconds guided by metronome and flat surface	Average normalised EMG amplitude for each of the 3 phases of humeral elevation (31-60°,61-90°, 91-120°), taken from the middle 3 of 5 trials
Moraes et al (2008)[380] (Onset times)	Standing, bilateral scaption, (30° ant to coronal plane) position guided flat surface. Performed at comfortable speed on verbal command	EMG onset times (relative to verbal command) determined as the point at which signal exceeded mean baseline by 2 SD for 50 ms.
Morais Faria et al (2008)[124] (%MVC_{EMG})	Standing, lowering the arms from full bilateral scaption (30° anterior to the frontal plane). Performed at 'comfortable speed' guided flat surface	Average normalised EMG amplitude from 3 repetitions of arm lowering, split into 6 phases: (1) full elevation to 150 degrees, (2)150-120°, (3)120-90°, (4) 90-60°, (5) 60-30° and (6)30-0°. Coactivation ratios also calculated.

Continued Table 2 – 17

Paper	Task (test procedures and functional movement)	EMG variables analysed
Reddy et al (2000)[10]	Scaption from 0-120° elevation, elbow straight, whilst holding a weight which is 25% of their NMW. 100° per second guided by metronome and flat surface (second beat of metronome full elevation, 3rd beat return to start).	Average normalised EMG amplitude for each phase of scaption (30-60°, 60-90° and 90-120°).
Wadsworth and Bullock-Saxton (1997)[73]	Standing, scaption to 160° (30° degrees anterior to the frontal plane). Guided by vertical guiders and metronome to achieve arc of movement per second.	EMG onset times (relative to movement) determined as point at which signal exceeded 5% of maximum amplitude (and visual determination for SA).

Table 2 - 18: Muscle activation level and onset compared between SIS patients and control from 9 studies (11 publications)

Paper	Patient	Control	Shoulder Muscles															
			AD	MD	PD	LS	UT	MT	LT	SA	LD	TM	PM	B B	SSP	ISP	SUBS	RM
EMG Activity Level																		
Bandholm	9	9	S	S	-	-	S	-	S	S	S	-	-	-	IM	IM	-	-
Ludewig	25	25	-	-	-	-	S	-	S	S	-	-	-	-	-	-	-	-
Brox	10	9	-	S	-	-	S	-	-	-	-	-	-	-	IM	-	-	-
Clisby	14	18	-	S	S	-	-	-	-	-	-	-	-	-	-	S	-	-
Cools	39	30	-	-	-	-	S	S	S	-	-	-	-	-	-	-	-	-
Morais	10	10	-	-	-	-	S	S	S	-	-	-	-	-	-	-	-	-
Finley	10	13	S	-	-	-	S	-	S	S	-	-	-	S	-	-	-	-
Reddy	15	15	-	IM	-	-	-	-	-	-	-	IM	-	-	IM	IM	IM	-
EMG Activity Onset time																		
Cools	As above		-	S*			S	S*	S*	-	-	-	-	-	-	-	-	-
Moraes	As above		-	-	-	-	S	S	S	S	-	-	-	-	-	-	-	-
Wadsworth	9	9	-	-	-	-	S	-	S	S	-	-	-	-	-	-	-	-

S = Surface electrodes

IM= Intra-muscular electrodes

* Both MT and LT muscles were found significantly delayed relative to MD muscle

Result of EMG activity (mean difference) in patients with SIS compared to controls

	No significant difference
MD	An increase in EMG activity at 25%MVC (observed but not reported)
MD	A significantly decreased EMG activity during 60-90° concentric scapation in Brox et al., and at 70%MVC in Redy et al. studies
UT	Increased EMG activity during loaded and unloaded scaption >90°
MT	A significant lower EMG activity during external rotation
LT	A significantly lower EMG activity
LT	A significantly greater EMG activity between 61° to 90 ° and >90°
SA	A significant decrease in activity of SA in Ludewig et al., study and a trend of decrease in other studies
LD	A significant increase in activity was demonstrated at 20%MVC between 45° to 60° degrees concentric abduction in subjects with SIS
ISP	Significantly decreased EMG activity during 30-90 concentric scapation for ISP
SUBS	A significant decrease in activity between 30° -60° of scaption

Compare the onset of muscle activation

	A highly significant delay in EMG onset

Table 2 - 19: Proposed Biomechanical Mechanisms of Clavicular, Scapular or Humeral Kinematic Deviations (adapted from Ludewig and Reynolds, 2009).

Mechanism	Associated Effects
Inadequate SA activation	Lesser scapular upward rotation and posterior tilt
Excess UT activation	Greater clavicular elevation, reduced scapular posterior tilt
Pectoralis minor tightness	Greater scapular internal rotation and anterior tilt
Posterior capsule tightness	Greater scapular anterior tilt, glenohumeral internal rotation deficit, greater humeral superior or anterior translation
Inadequate rotator cuff activation or partial tearing	Greater humeral superior translation, lesser humeral external rotation
Pectoralis major tightness	Lesser clavicular retraction, greater humeral internal rotation
Thoracic kyphosis or flexed posture	Greater scapular internal rotation and anterior tilt, lesser scapular upward rotation

2.20 Electromyography and Muscle Fatigue

2.20.1 Concept of Muscle Fatigue

Fatigue is a daily living experience, but its definition in the clinical context is very complex. Vollestad (1997)[381] defined muscle fatigue as any exercise-induced reduction in the capacity to generate force or power output. Skeletal muscle fatigue is a reversible phenomenon that is characterized by an initial subclinical phase, followed by a progressive clinical one and may eventually reach a point of failure of performance.

The initial subclinical phase occurs at the cellular level where ionic and metabolic changes take place since the very beginning of muscle effort. The clinical phase may be described as a feeling or sensation of weakness, muscle pain and progressive decline in force, velocity and accuracy of a performed task[382]. The progress of fatigue during these phases is based on the intensity and duration of the muscle activity.

Generally, EMG is a good diagnostic tool to measure muscle fatigue which could be induced either by a sustained maximal or even submaximal effort. Of course, the myoelectric changes and decline in performance is not immediately apparent if a submaximal activity is performed, and in this situation fatigue manifests itself as inability to continue the activity at the original intensity[383]. Muscle fatigue is a protective mechanism that prevents mechanical and biochemical damage to occur in a muscle, which recovers its normal activity after a sufficient period of rest.

2.20.2 Classification

There are numerous EMG studies on muscle fatigue but with confusing outcomes, probably due to existence of different kinds of fatigue. Analysis of changes in MU potential or M-wave size and shape with fatigue suggests peripheral factors that contribute (together with the central factors) to changes in amplitude and spectral characteristics of EMG signals[347].

2.20.2.1 Central Fatigue

Central fatigue is defined as any exercise-induced reduction in maximal voluntary contraction force which is not accompanied by the same reduction in maximal evocable force that is defined as the force generated by a muscle or group of muscles when additional electrical stimulation does not augment force[381].

Normally a muscle activity commences as a central command at the level of the motor cortex or as a reflex signal starts at the spinal cord[384,385]. In the classic study by Merton (1954)[386] on the human adductor pollicise the reduced force production in a prolonged voluntary contraction could not be improved by direct motor nerve stimulation and it was concluded that reduced central drive and impaired neuromuscular transmission were unimportant. Recently, Kremenic et al. (2009)[387] used peripheral magnetic stimulation to evaluate central fatigue on 11 trained male cyclists and demonstrated that the cyclists experienced significant central fatigue during prolonged cycling[387].

Change in surface EMG activity may reflect changes in motor unit recruitment strategy by the CNS and/or peripheral changes, such as impairments in neuromuscular transmission or action potential propagation along the muscle fibres. Normalization of the integrated EMG signal to the M-wave (muscle compound action potential) amplitude or area is used to minimize peripheral contamination and hence enhance the sensitivity of this method to assess the level of central motor output[388].

2.20.2.2 Local Muscle Fatigue

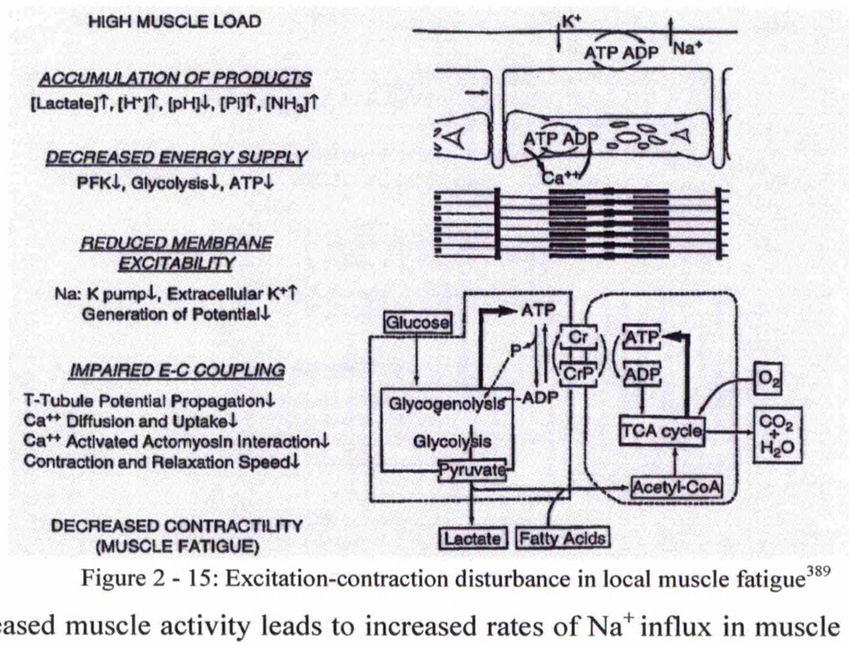


Figure 2 - 15: Excitation-contraction disturbance in local muscle fatigue[389]

Increased muscle activity leads to increased rates of Na^+ influx in muscle fibres and K^+ efflux from them. The finding that K^+ is accumulated extra-cellularly and Na^+ intra-cellularly suggests that activation of the Na^+-K^+ pump is insufficient[390], or that the pump capacity is limited. Increased extra-cellular K^+ induces a decrease in the membrane potential and causes a reduced amplitude and propagation velocity of IAP[391]. Since IAP is the first step in the chain of excitation contracting events[392], it has been suggested that alteration in sarcolemma function induces muscle fatigue by preventing cell activation[393]. Edwards has suggested that cell depolarization would provide a safety mechanism to protect the cell against ATP depletion and Ca^{2+} accumulation[389] [Figure 2 – 15].

Furthermore, several studies reported the effect of blood flow on muscle activity and demonstrated that, even at quite low force levels (10-15% of MVC); the muscle has inadequate blood supply possibly due to increased intramuscular pressure above normal capillary perfusion[394,395]. In daily activity, the muscle contraction is intermittent, so that sufficient blood flow with oxygen will maintain the aerobic metabolic pathways for sufficient ATPs[396-398].

2.20.3 Electromyography Power Spectrum and Muscle Fatigue

Piper (1912)[399] was the first who observed a reduction in frequency (slowing of rhythm) as recorded by the string galvanometer and during a sustained forearm muscle contraction using a dynamometer. Eleven years later Cobb and Forbes (1923)[400] found an increase in amplitude of individual action-currents in EMG of rapidly fatigued muscles. Since then, the studies can be divided into investigations directed at discovering myoelectric signs of fatigue and/or causes for fatigue[347].

The EMG parameters such as RMS MnF and MdF are commonly used to assess the myoelectrical changes of a fatigued muscle as well as the input of CNS to that muscle. However, these estimators are influenced not only by CNS input, but also by peripheral muscle properties[401]. The EMG power spectrum is influenced by many factors such as the force level, temperature, action potential conduction velocity, firing rate and synchronization of active motor units as well as type of contraction. On the assessment of muscle fatigue based on EMG power spectrum, the conditions must be comparable to evaluate possible differences in the spectrum as a result of muscle fatigue per se. This is fulfilled when registrations of muscle fatigue are performed during isometric contractions[402].

Surface EMG is a summation signal from a large number of motor units that reflects the activity in the whole muscle, while intramuscular EMG represents a more specific part of the muscle. By simultaneous surface and intramuscular EMG recordings, it is possible to elucidate to what extent the surface EMG registered in the field mirrors the intramuscular EMG[402]. Christensen and colleagues (1995)[402] recorded the EMG power spectrum from the BB with simultaneous use to surface and intramuscular FW electrodes. Differences in the power spectrum as reflected by MnF and MdF was attributed to the variation between the distance of surface electrodes[403]; together with the low-pass filter effect because of subcutaneous fat.

2.20.4 Electromyography and Muscle Fatigue in Normal Daily Life

A survey was conducted on musculoskeletal and fatigue symptoms related to individual and work-related risk factors among middle-aged female workers in a frozen food processing factory by using a self-administered questionnaire. Proportions of workers who frequently experienced, during the last one month, stiff muscle or pain in the neck-shoulder, back and lower limbs were 32.9%, 26.8% and 15.9%, respectively. The proportion for fatigue symptom was 30.5%. Factors related to fatigue were: short duration of employment , light body weight, long house work, short sleep hours, walking to and from work, those related to back pain were: high body height, light body weight, those related to lower limb symptom were: working height below hip height, working height above shoulder height, high body height and low body height[404]. Following a task to fatigue SA on 28 asymptomatic participants, higher mean activation levels were observed in UT in contrast to SA and LT. Higher mean of UT activation may be compensatory for fatigue of other shoulder muscles and may reflect fibre type or central control mechanisms[405].

2.20.5 Electromyography and Muscle Fatigue in Patients with Subacromial Impingement Syndrome

A number of studies have identified occupational risk factors that are associated with musculoskeletal disorders. In particular, repetitive movements, prolonged static load on the muscles and extreme working postures are considered physical work-related risk factors[406]. It is, however, remarkable that even very low loads and even in the absence of awkward body posture work-related upper extremity disorders may occur[407]. Chronic pain may lead to the impairment of the normally first recruited low-threshold MUs and it is known as 'the Cinderella Hypothesis'[408]. The Cinderella hypothesis implies that long periods of activation without sufficient relaxation of the muscle will result in muscle fibre damage and muscle-related pain. The Cinderella hypothesis was the main research topic of the European Concerted Action 'Procid' and during its 3 years duration substantial evidence has been gathered that the hypothesis has a valid scientific basis[409,410].

Kallenberg et al. (2007)[411] investigated the UT on the dominant side using EMG signs during a sustained fatigue-developing task in 10 healthy volunteers and 10 workers with chronic neck-shoulder pain. They observed less myoelectric response in patients to the fatiguing task than controls (i.e. less increase in RMS, decrease in MdF and decrease in CV). Their explanation was that patients with chronic pain have already fatigued or impaired low-threshold MUs[408]; therefore, higher-threshold MUs would be recruited to maintain required force. The additional recruitment may mask the myoelectric manifestations[412].

2.20.6 Factors Influencing Muscle Fatigue

(1) Task-dependent factors in fatigue of human voluntary contractions. The fatigue is not caused uniquely by any common set of factors, but rather the amount of stress placed on each site depends on the type of exercise from which fatigue develops. Perhaps the neuromuscular system as a whole is so well adjusted that any task-related additional impairment at one site is compensated by corresponding functional improvements at others. We suggest that nature has had a long time in which to 'get it right'[413].

(2) A fatigue-induced reflex inhibition of motorneurone firing rates. These are inhibited by a reflex from the muscle during fatigue[414].

(3) Changes in muscle contractile properties and neural control during human muscular fatigue. Evidence is presented that, in fatigue of sustained maximal voluntary contractions (MVC) executed by well-motivated subjects, the reduction in force-generating capacity need not be due to a decline in CNS motor drive or to failing neuromuscular transmission, but can be attributed solely to contractile failure of the muscles involved[415]. However, despite this conclusion, both the integrated EMG and the mean firing rate of individual motor units do decline progressively during sustained MVC. This, however, does not necessarily result in loss of force since the parallel slowing of muscle contractile speed reduces tetanic fusion frequency. It is suggested that the range of motoneuron firing rates elicited by

voluntary effort is regulated and limited for each muscle to the minimum required for maximum force generation, thus preventing neuromuscular transmission failure and optimizing motor control. Such a CNS regulating mechanism would probably require some reflex feedback from the muscle[416].

(4) Contractile speed and EMG changes during fatigue of sustained MVC. During a 60 seconds sustained MVC, there is a progressive slowing of contraction speed such that the excitation rate required to give maximal force generation is reduced. The simultaneous decline in EMG may be due to a continuous reduction in motoneuron discharge rate, and the EMG decline may not necessarily contribute to force loss[415].

2.21 Electromyography General Considerations

2.21.1 Cross Talk

It is theoretically possible to detect the electrical signal that emanates from an active muscle fibre at any point within the tissue[111]. However, the amplitude of the detected signal decreases as the distance between the active muscle fibre and the electrode increases[417]. The detection of myoelectric signals from muscles other than the muscle directly underneath the surface electrode is known as cross talk and may lead to confounding interpretations of EMG signals. Placing the electrode centred on the aimed muscle, away from its edges and oriented parallel to the muscle fibres reduces the phenomenon of 'cross-talk'[418]. Fine wire electrodes, with a significantly smaller pick-up area, are less susceptible to cross talk[419].

2.21.2 Electrode Selectivity and Pick-Up Area

The pick-up area represents an area in which all electrical signals will be detected by the electrode. Thus, surface electrodes with smaller pick-up areas represent electrodes that are selective. A bipolar electrode configuration has a smaller pick-up area than a monopolar configuration[111].

2.21.3 Electrodes Size

The electrode size is defined by 'Surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) group' as the size of the conductive area of a surface electrode. The circular bipolar detectors of 1 cm diameter are recommended as the electrodes are able to pick the deep myoelectric signals rather others from surroundings[420].

2.21.4 Electrocardiogram Interference

The highly organised electrical activity of the heart has the potential to contaminate signals obtained from the shoulder musculature, particularly on the left side of the body. Due to the location of electrodes, ECG contamination may be present in the signal obtained from the SA, LD, TM, PM and to a lesser extent the UT. ECG reduction algorithms are available which selectively eliminate ECG artefact spikes. The algorithms combine pattern recognition and adaptive filtering. An area of contaminated signal recorded while the subject is at rest can be utilised to remove the ECG artefact from the remaining signals[345].

3 CHAPTER THREE: MATERIAL AND METHODS

3.1 Study Design

A case-control study of subjects with and without Subacromial Impingement Syndrome (SIS)

3.2 Site of Study

The study was conducted initially in the physiotherapy department of the Royal Liverpool Hospital (September 2009 - February 2010) and then in the EMG room at the Magnetic Resonance and Imaging Analysis Research Centre (MARIARC), University of Liverpool (September 2010 - January 2011).

3.3 Ethical Approval

The study was approved by the local research ethics committee (NRES Committee North West – Liverpool Central).

3.4 Subjects

3.4.1 Recruitment

The healthy volunteers 'Control Group (CP)', included university students and staff, as well as other workers in the society who were recruited through University of Liverpool intranet announcements and other public centres. The controls had no medical history of upper extremity, neck and back problems confirmed during interviews and clinical assessments.

The patients with the diagnosis of SIS were identified and recruited through the Physiotherapy department and Upper Limb Unit at the Royal Liverpool and Broadgreen University Hospitals who had been clinically assessed by an upper limb physiotherapist or consultant.

3.4.2 Patient Inclusion Criteria

Patients with persisting shoulder pain for at least 12 weeks and revealed positive clinical tests for SIS were included.

3.4.3 Patient Exclusion Criteria

Patients with previous treatment other than medication for pain during the last three months, clinical evidence of hypermobility syndrome, osteoarthritis of the GHJ, systemic diseases that may affect the function of neck, back and upper limb; and major trauma to the upper limb during the last 6 months were excluded.

More details of the study groups are provided in chapter four (Participants)

3.4.4 Participant's Information Package

Potential participants from healthy volunteers and patients received invitation letter to take part in the study and provided with a 'participant information package' containing details on the study venue, experimental protocol and involved measurements, and any possible risks. They were given sufficient time to review the package and have their questions answered before making a final decision on participation in the study.

3.4.5 Sample Size

The sample size of 34 healthy controls and 39 patients with the diagnosis of SIS was considered sufficient to provide 80% power to detect differences of 5 degrees or 10% of maximal voluntary contraction (MVC), mean amplitude, median frequency or slope between the groups of interest.

3.5 Consent Form

On attending the site of study, the experimental protocol, procedures including video recording, and confidentiality of data were explained to the participants. All participants gave their consent by signing an approved consent form prior to taking part in the study.

3.6 Methods

The experimental measurements were grouped into non-EMG and EMG tests. The non-EMG section, which lasted about 2 hours, involved the assurance, clarification of any doubts, a comprehensive clinical assessment, completion of patient-rated questionnaires and scores, and measurements of upper body posture, muscle strength and functional impairment. The EMG section lasted between 90 minutes to 2 hours and included electrode placement, manual muscle testing, and different EMG recording protocols designed for the assessment of muscle activation patterns and muscle fatigue. Participants were given the options of completing experiments either in one or two sessions.

3.6.1 Clinical Assessment

3.6.1.1 History and Physical Examination

The medical history and physical examination were documented on a study-specific data collection form [Appendix I] and recorded on video files for all participants. Physical examination included points of tenderness, active and passive range of motion and a set of general and disease-specific clinical tests [Table 2 - 7, Table 2 - 8, Table 2 - 9 and Appendix III], which allow proper diagnostic approach to SIS in patients and ensure the absence of clinical findings in healthy controls.

3.6.2 Questionnaires

A combination of upper extremity and generic questionnaires were used to provide further information on pain, functional impairment, alterations in daily living activities, and quality of life from participants' perception. These questionnaires and scores were completed at the time of rest between different experiments. Every questionnaire was provided with clear self-explaining statements for easy reading, understanding and completion. Further clarifications were provided by the investigator as appropriate [Appendix I].

3.6.2.1 Constant - Murley Score

The Constant - Murley Score (CMS) is a validated and widely used shoulder-specific evaluation scale, which combines subjective and clinical assessments. It includes inquiries about intensity of pain (15 points), daily living activities (20 points), range of motion (40 points) and power (25 points)[278]. The total score is 100 (normal status).

3.6.2.2 Oxford Shoulder Score

The Oxford Shoulder Score (OSS) is a shoulder-specific tool originally designed by Dawson et al. (1995)[421] for measuring the outcome of non-stabilizing shoulder surgery. The original study included 111 of patients, 79 (67.5%) diagnosed as having an impingement syndrome with or without a rotator cuff tear. The OSS is widely used in many countries and extended to include patient-report outcome from chronic inflammatory and degenerative diseases, therefore, recommendations were raised to review the items and change the scoring system[283]. There are 12 item in this tool with individual score of 0 (the worst) – 4 (the best) and a total score of 48.

3.6.2.3 Upper Limb Function Index

The Upper Limb Function Index (ULFI) is a validated specific instrument for the upper limb that can be completed by the patient to indicate the status of functional loss[287]. It includes 25 statements which focus on the upper extremity dysfunction and related changes in health. The individual scores are added and multiplied by 4 to obtain a maximum of 100% which indicates the worst function.

3.6.2.4 The Disability of the Arm, Shoulder and Hand

The Disability of the Arm, Shoulder and Hand (DASH) was developed by American Academy of Orthopaedic Surgeons (AAOS) along with Institute for Work & Health (Toronto, Ontario, Canada) to assess upper extremity-related symptoms and measure functional status at the level of disability[285]. The DASH is a 30-item questionnaire covering symptoms (pain, weakness, stiffness and tingling/numbness); daily and recreational activities, social interaction and psychological function with 2 optional modules related to the work and sports. The total score for the 30 item is 100 (the worst function) and each optional modules maximally scores 100 (the worst function). A DASH score may not be calculated if there are more than 3 missing items.

3.6.2.5 General Health SF-12

The General Health SF-12 (GHSF-12) is a 12-item health survey, which is used to quantify the impact of health on performance. Scoring algorithms from the general population are used to score 12-item versions of the two components (Physical Components Summary and Mental Component Summary)[422].

3.6.2.6 Hospital Anxiety and Depression Scale

HADS is a valid, reliable and practical tool that is used to identify and quantify the two most common forms of psychological disturbances in medical patients. It consists of 7 items anxiety and seven depression components)[288].

The HADS consists of 7 items relating to anxiety and 7 items relating to depression, with both subsets intermingled within the questionnaire. Each item is rated as follows: 'Yes definitely', 'Yes sometimes', 'No, not much', or 'No, not at all'. Each response is scored from 0-3 depending on the wording of the question. The total score for the depression subscale is the combined score for each of the questions relating to depression. Similarly, the total anxiety score is calculated in the same manner. According to Zigmond (1983)[288], a score of 7 or less represents a non-case, scores of 8-10 doubtful cases and scores of 11 and above definitive cases.

3.6.2.7 McGill Pain Questionnaire

The McGill Pain Questionnaire (MPQ) addresses the character of pain and intensity that needs consideration. MPQ collates words used to describe pain, categorises them and assigns them to a common intensity dimension[298]. Subjects are instructed to select one word from each category that best describes their present pain. If a category is not applicable, this is left out. Part 2 of the questionnaire relates to the pattern of pain and part 3 to pain intensity. Part 3 utilises the words mild (1 point), discomforting, distressing, horrible and excruciating (5 points) to describe Present Pain Intensity (PPI). The questionnaire sensitivity and construct validity has been reported [423,300]. A number of scores are deducible from the questionnaire, 6 relating to pain quality and 1 relating to pain intensity[299]. However, the three main measures are the Pain Rating Index (PRI), Number of Words Chosen (NWC) and the PPI. The scoring of the first and third measures was used as illustrated in Table 3–1.

Table 3 - 1: The scoring system used for the major outcomes of the McGill pain questionnaire

Part	Range	Description
Pain Rating Index (PRI)	0-78	The sum of the words chosen in the different categories of sensory, affective, evaluative and miscellaneous groups
Present Pain Intensity (PPI)	1-30	The scale

3.6.3 Measurement of Muscle Strength (Isometric Maximum Voluntary Contraction)

3.6.3.1 Equipment

Mecmesin Shoulder myometer [Figure 3 – 1] and Emperor Lite software (Mecmesin Ltd. Slinfold, UK) was used to measure and record the strength of different shoulder muscle groups. The myometer has an accuracy of ± 0.1% of full-scale and 1000 N capacity. The data could be real-time seen on a digital display screen. The myometer was fixed on an extension arm attached to a chair designed for the strength measurements. The extension arm is mobile and can be adjusted to the participant's upper limb position and length. The isometric MVC was measured in Newton (N) units with a feedback on the computer screen[424,425].

Figure 3 - 1: Nottingham Mecmesin myometer

3.6.3.2 Protocol

Participants were seated in upright position with both hips and knees flexed to 90° and feet apart and flat on the ground. Strength was measured bilaterally in four standard movements: (1) foreward elevation with the shoulder at 90° flexion, elbow in extension and the forearm in pronation [Figure 3 - 3A], (2) scapular plane elevation with the shoulder at 90° of abduction, elbow in extension and the hand in 'full can' position [Figure 3 - 3B], (3) and (4) External and Internal rotation with the shoulder in neutral position, the elbow in 90° flexion tucked to the side of the body and the forearm in neutral position [Figure 3 - 3C and D]. The strap of Mecmesin myometer was placed at the wrist level.

After measurement-related instructions, participants were allowed to familiarise themselves with the myometer and the feedback on the computer screen. Both shoulders were tested three times for 5 seconds with 60 seconds rest in between the measurements[133,426]. During the experiment subjects received verbal encouragement in order to improve maximal muscle contraction. The order of movement measured was chosen randomly. The maximum of the three measurements is considered 100% MVC. The strength measurement protocol is summarised in Figure 3 - 2.

Measuring Shoulder Girdle Muscle Strength

Position	Sitting on a designed chair for the study which allows standardized body and upper limb positioning for the measurements.
Myometer	Mecmesin Myometer fixed on an extension arm attached to the chair and adjusted according to the upper limb position. The myometer strap always placed at the wrist.
Maximum Voluntary Isometric Contraction (MVIC)	Both shoulders were tested. The subjects perform 3 trials each lasts for 5 seconds of MVIC of the following muscle groups: GHJ flexors (90° GH flexion, 0° elbow extension, and forearm in pronation) GHJ abductors (90° abduction in the scapular plane, 0° elbow extension and hand in pronation). External rotators (the arm along the side of the body, elbow at 90° flexion, and forearm in neutral rotation). Internal rotators (the same position as for external rotators).
Rest	The subjects have 60 seconds rest in between every three trials.
Average MVC	The averaged MVIC for each 3 trials is calculated and recorded in the data collection form.

Figure 3 - 2: Measurements of muscle strength

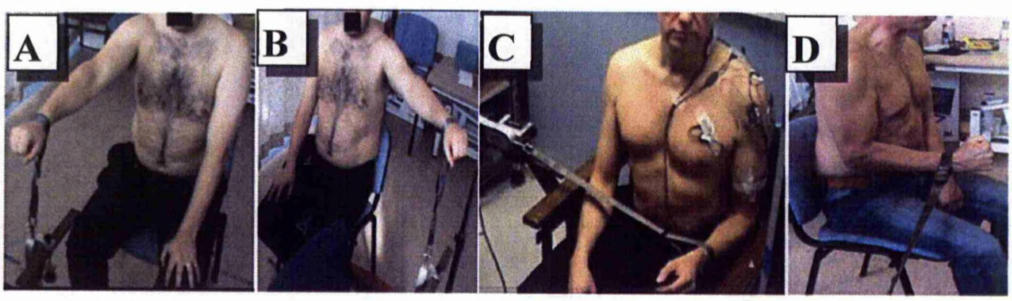


Figure 3 - 3: Muscle strength measurements.

(A) Isometric MVC at 90° right shoulder flexion, (B) isometric MVC at 90° left shoulder abduction in scapular plane, (C) isometric MVC at left shoulder external rotation, and (D) isometric MVC at right shoulder internal rotation

3.6.4 Postural Measurements

The distance between specific reference points around the shoulder reflects the position of the scapula and its relation to the axial spine and allows the comparison of anterior soft tissue length with the soft tissue on posterior aspect[103,427,428]. Lateral scapular slide test indicates of rhythmic motion of the scapula and humerus[18,15]. All these measurements were performed bilaterally.

3.6.4.1 Measurement Tools

The tools included: (1) a measurement tape to measure distance between reference points and record it to the nearest millimetre, (2) a flexicurve ruler to measure the length and depth of the thoracic spine (C7 to T12 spinous process) [Figure 3 - 4], (3) a plumb line as a vertical reference, (4) non-allergenic adhesive markers of 6.5 mm in diameter to mark the reference bony landmarks and (5) a Sony camera used to draw and measure angels of interest.

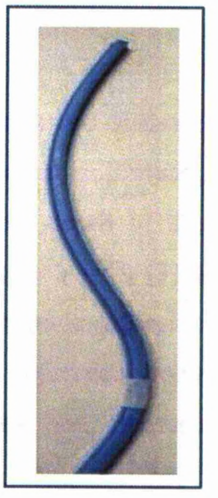


Figure 3 - 4: Flexicurve ruler

3.6.4.1.1 Position and Preparation

Each subject stood 30 cm in front of a plumb line hanging from the ceiling, and 20 cm away from a wall on their side. The position was marked on the floor to keep it consistent for all participants. The following bony prominences were palpated and identified with the non-allergenic adhesive markers: (1) the posterior-lateral angle of the acromion (point A), (2) root of the spine of the scapula (point B), (3) the inferior angle of the scapula (point C), (4) thoracic spinous process levelled with the posterior-lateral angle of the acromion (point D), (5) thoracic spinous process corresponding with the root of the spine of the scapula (point E), (6) thoracic spinous process corresponding to the inferior angle of the scapula (point F), (7) tragus of the ear (point G), (8) seventh cervical (C7) spinous process to which a 3-cm straw marker was attached (point H), (9) mid-point of the humeral head was a point half-way between the acromion process and posterior acromial angle and 4 cm downward on the lateral aspect of the shoulder (point I), (10) mid-point of the sternal notch (point J), and (11) the tip of the coracoid process (point K) [Figure 3 - 5].

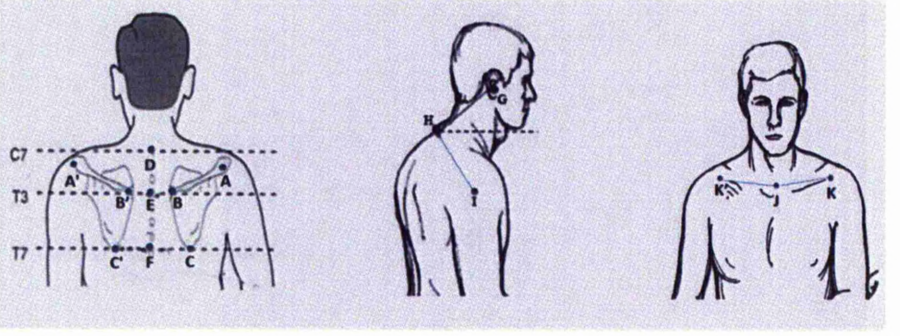


Figure 3 - 5: Reference point for postural measurements

3.6.4.2 Measurement Protocol

The participants were asked to do relaxing exercise and adopt a comfortable standing position. Five sets of measurements were performed on every subject: (1) FHP and FSP angels, (2) scapular protraction, (3) Scapular index, (4) lateral scapular slide test, and (5) thoracic kyphosis index. All measurements were repeated 3 times, averaged and recorded [Appendix I].

3.6.4.3 Measurement of the Forward Head Posture and Forward Shoulder Posture Angels

A lateral photograph was taken for the cervicothoracic region with a digital Sony Camera, set at 100 ASA and a 28- to 50-mm adjustable lens[103]. The camera was placed 2 meters from the subject and mounted on a levelled tripod. The C7 marker was placed approximately in the centre of the lens in order to eliminate lens error. The base of the camera was parallel to the ground and the front of the camera was parallel to the facing wall to minimize parallax error [Figure 3 - 6]. This procedure has been used in previous published studies[154].

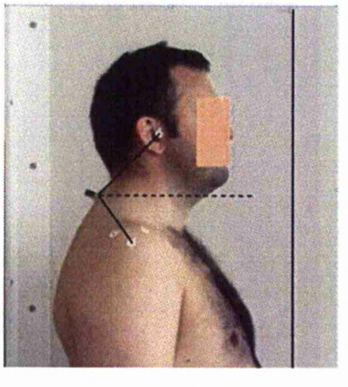


Figure 3 - 6: Measurement of forward head posture and forward shoulder posture angels

3.6.4.4 Measurement of Normalized Scapular Protraction

Using a measuring tape, the distances AE and A'E then AB and A'B' were measured as shown in Figure 3 - 7. Those measurements were used to evaluate the normalized scapular protraction (NSP), by dividing the length AE by the length AB and A'E by A'B'.

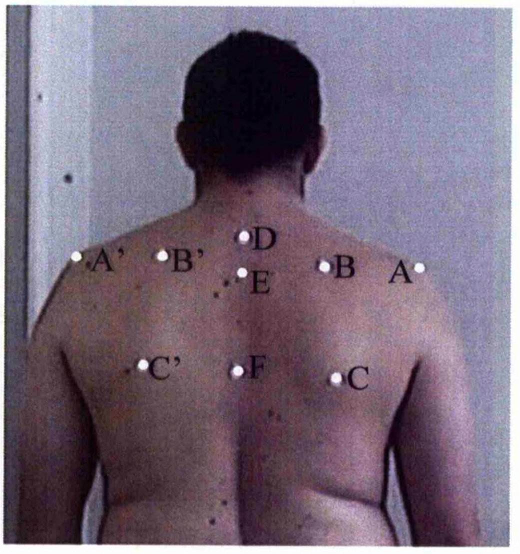


Figure 3 - 7: Reference points for the measurements of posture

Using normalized protraction ratio reduced the impact of relative body size of an individual on the results. A larger value for the normalized protraction ratio would indicate that the scapula is relatively more protracted.

3.6.4.5 Scapular Index

The distance from the mid-point of the sternal notch (J) to the medial aspect of the coracoid process on each side (K, K') and the horizontal distance from the posterolateral angle of the acromion on each side (A, A') to the thoracic spine (D) were measured [Figure 3 - 5 and Figure 3 - 7]. The scapula index (SI) was calculated on each side as a potential clinical measurement indicating pectoralis minor influence on scapular position, using the equation: [(J) to (K)/(A) to (D) x 100] on the right side and [(J) to (K')/(A') to (D) x 100] on the left side[429].

3.6.4.6 The Lateral Scapular Slide Test

LSST was based on the measurement of the distance between the inferior angle of each scapula [Figure 3 - 7, point C and C'] and the nearest thoracic spinous process [Figure 3 - 7, point F][218]. The measurements were taken in three different positions, repeated three times, and averaged. In the first position, subject's arm was placed at the sides in the anatomical resting position [Figure 3 - 8A]. In the second position, the arms were placed on the hips, with the fingers anterior and the thumb posterior [Figure 3 - 8B][218]. In the third position, the arm was elevated 90° with maximal internal rotation (thumb to floor) at the GHJ [Figure 3 - 8C].

A B C

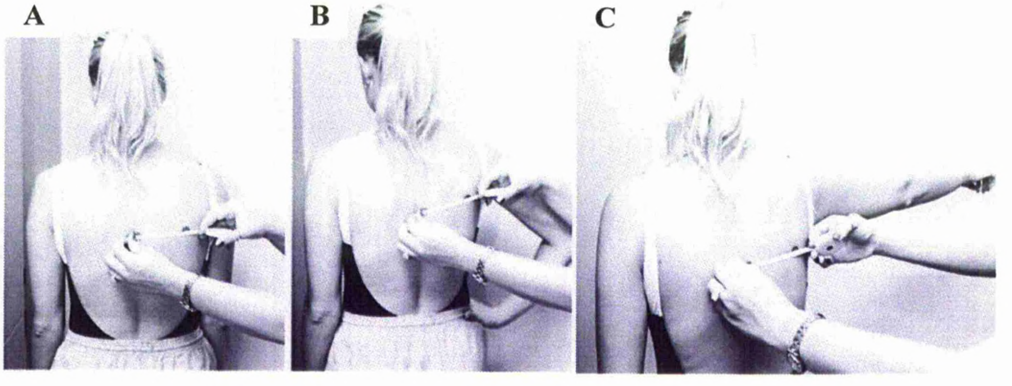


Figure 3 - 8: Measurements of Lateral Scapular Sliding Test

(A) Arm at the side, (B) Arm abducted with hand at waist, (C) Arm in 90° scaption and IR

3.6.4.7 Thoracic Kyphosis Index

In a standing position, the subject's thoracic spine curvature was measured by locating the C7 and T12 and placing a flexible ruler along the contour of the spine between those landmarks. The ruler was then marked at C7 and T12 before removing it from the subject. The depth of the curve was divided by the height of the curve to determine the thoracic kyphosis index (TKI) [Figure 3 - 9][430].

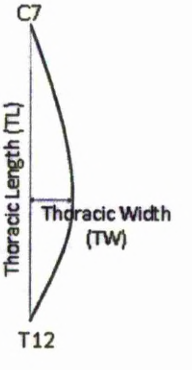


Figure 3 - 9: Flexicurve measurements of the thoracic kyphosis index

3.6.5 Functional Impairment Test–Hand and Neck/Shoulder/Arm

The Functional Impairment Test-Head and Neck/Shoulder/Arm (FIT-HaNSA) has been designed to assess the upper limb function during 3 tasks which simulate daily living activities of forward reaching in different levels and overhead work[58]. Initially, the test was refined based on a pilot tested 5 patients with severe shoulder impingement and matched to controls, followed by reliability assessment on 10 healthy subjects and finally validated on 17 patients with mild to moderate shoulder pathology[58]. Furthermore, the reliability and validity were reconfirmed on a larger group of participants including 36 patients with shoulder disorders and 65 healthy subjects[431]. All participants followed the protocol as recommended by MacDermid et al. (2007)[58] and outlined in Appendix V.

3.6.5.1 Testing Apparatus

A purpose built shelving system was prepared by the Clinical Engineering Department (Royal Liverpool University Hospital, UK) as a requirement for an MPhil protocol on the factors influencing the shoulder function in patients with massive rotator cuff tears (Hawkes, 2009)[374]. The specifications of this shelving system were similar to that described by MacDermid et al. (2007)[58] [Figure 3 - 10A]. The system was a frame-like mobile unit and weighted at the bottom for stability. The shelves were adjustable and were set at desirable levels stated in the protocol and in accordance with the participant's waist and eye levels. In the first two tasks, three 1 kg containers were placed on the lower shelf and 25 cm apart. The containers' position was visually guided by three rounded coloured markers [Figure 3 - 10D].

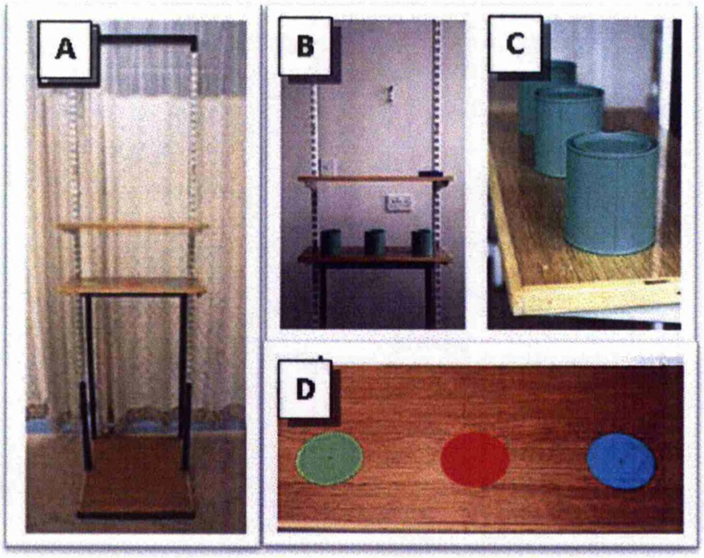


Figure 3 - 10: Functional impingement test-hand and neck/shoulder/arm (FIT-HaNSA) shelving system

Purpose built shelving system designed for the FIT-HaNSA functional performance test. A – Shelving unit; B – shelves (with weights) set 25 cm apart; C – three 1kg weights; D – coloured markers used to guide weight placement

An additional perpendicular plate could be easily and securely attached to the top shelve for the third task. The plate had three holes where two bolts and their nuts could inter-change their positions. Extra bolt and nut were kept for need [Figure 3 - 11].

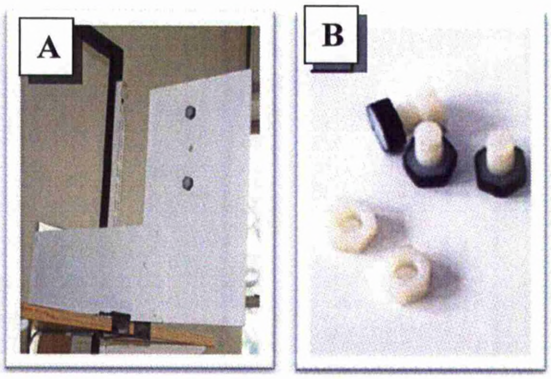


Figure 3 - 11: Functional impingement test-hand and neck/shoulder/arm (FIT-HaNSA) dexterity plate, bolts and nuts

(A) Dexterity plate attached to the shelf; (B) bolts (black) and nuts (white) used as part of 'Task 3 – overhead work'.

3.6.5.2 Testing Protocol

The participant stood up-right with the feet apart and flat on the ground. The distance from the apparatus was set as the elbow tucked at the side and the tip of the index finger just touched the shelf at the waist level. This position was maintained in all tasks.

The 'waist-up' task (WUT) was performed first, using the dominant or non-dominant hand in healthy volunteers and the affected hand in patients. Three weights were lifted sequentially from the lower shelf at the waist level to the higher shelf 25 cm above the lower one and then returned to the lower shelf. The pace was governed by a metronome set to 60 beats per minute. Beat 1 corresponds with lower shelf contact and beat 2 with higher shelf contact [Figure 3 - 12A and Table 3 - 2].

The 'eye-down' task (EDT) was performed after 30 seconds of rest following the first task. The higher shelf was placed at the eye level and the lower one was adjusted 25 cm below. The three weights were lifted sequentially from the lower to the higher shelf, guided by the metronome and coloured spots on the shelves [Figure 3 - 12B and Table 3 - 2].

The 'over-head' task (OHT) was performed after 30 seconds of rest following the second task. The participant was facing the perpendicular plate which was placed and secured on the shelf at the eye level. Initially one bolt was placed at the upper hole and the second at the lower one. The bolts are arranged so that the standoff and nuts are on alternating side. The subject used both hands together to unscrew the top bolt and move it to the middle hole, unscrews the second bolt and moved it to the upper hole and again the first bolt was moved to the lower hole. That pattern was repeated sequentially for 5 minutes [Figure 3 - 12C and Table 3 - 2].

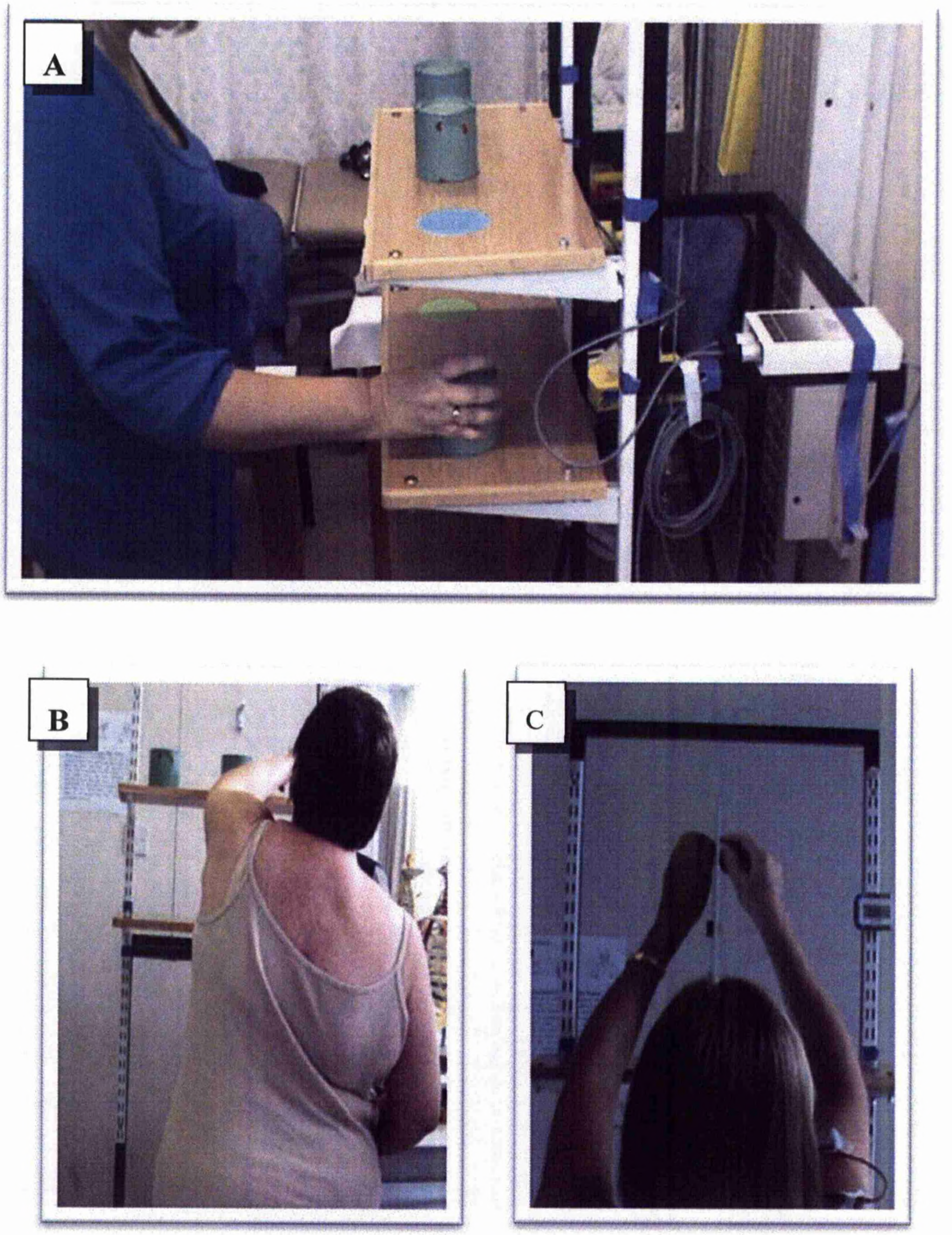


Figure 3 - 12: Function impairment test-hand and neck/shoulder/arm.

The three tasks include: (A) Waist-up task, (B) eye-down task and (C) over-head task.

Table 3 - 2: Protocol Summary of functional impairment test-hand and neck/shoulder/arm

Task and Rest	Lower Shelf Position	Higher shelf position	Action	Guide	Duration
First: Waist-up Task	Waist level	25 cm above the lower shelf	Lifting 3 weights from lower to higher shelf and return	Metronome set to 60 beats/minute Coloured spots on shelves	5 minutes
Rest			Relax		30 seconds.
Second: Eye-down Task	25 cm below the higher shelf	Eye-level	Lifting 3 weights from lower to higher shelf and return	Metronome set to 60 beats/min Coloured spots on shelves	5 minutes
Rest			Relax		30 seconds.
Third: Over-head Task	No	Eye-level with perpendicular plate	Moving two bolts between three holes in rotation	Holes in the perpendicular plate	5 minutes

Each task was performed for 5 minutes or until the test stopping criteria were met[58]. The stopping criteria include:

1. The subject stops or states it is too painful to continue.
2. The subject is severely off pacing to the extent that they are unable to complete one repetition of the movement within 2 beats of the metronome.
3. The subject substitutes using trunk/whole body movement and cannot correct with feedback for 5 successive repetitions of the task.
4. The examiner believes the subject is at risk of injury or adverse complication if tests were to continue.

3.6.5.3 Scoring

The time the participant took for each task was registered, on data collection form, using a stopwatch (in seconds). The score for each task was presented as a percentage with 100% representing the best function. The total FIT-HaNSA score was determined by calculating the mean of the scores of the 3 individual tasks.

3.6.6 Electromyography

3.6.6.1 Electromyography Equipment

A 16-channel wireless TeleMyo 2400T G2 system (Noraxon, Arizona, USA) was used for EMG data acquisition. The myoelectric signals were picked by bipolar surface and fine-wire electrodes, connected via pre-amplified leads to the Telemyo 2400T G2 transmitter, and transmitted wirelessly (WiFi) to the PC through a USB powered mini-receiver. The transmitter was fastened around the participant's waist to allow free mobility during a given task. [Figure 3 - 13].

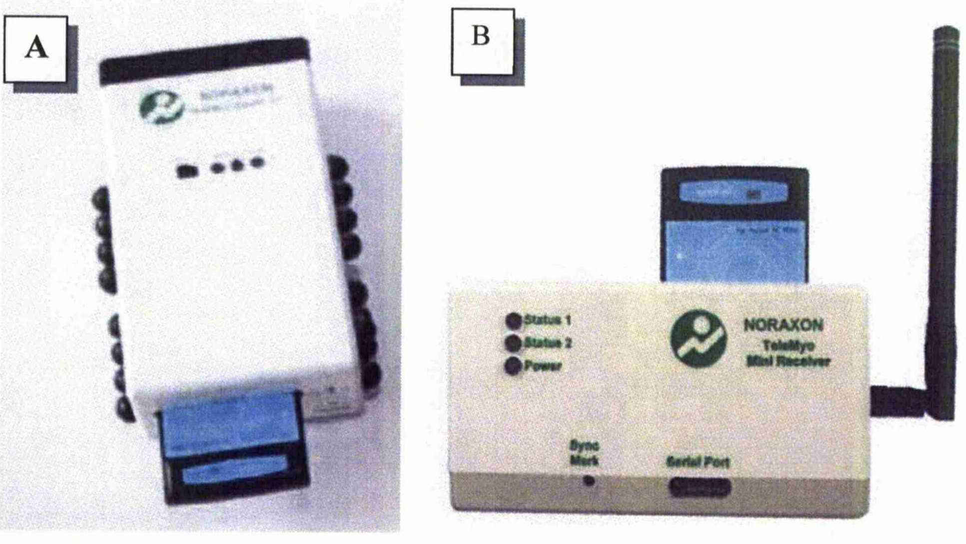


Figure 3 - 13: Noraxon TeleMyo Electromyograph system

(A) TeleMyo 2400 G2 Telemetry (16-channel transmitter) and (B) TeleMyo mini-receiver

Noraxon's MyoResearch XP software (1.08.17 Master Edition) was used to control basic settings of the system, synchronize video camera and store real-time EMG data and video records. In addition, the software allows offline data processing, analyses and interpretation.

3.6.6.2 Basic Settings

The study used a combination of surface and fine-wire electrodes to collect EMG signals from 15 superficial and deep shoulder muscles. Therefore, the sampling frequency rate and high frequency cut off were set as 3000Hz and 1500Hz, respectively based on the Nyquist Theorem[432,433]. The Band pass filtering was performed off-line 10-500Hz for surface and 10-1500Hz for the fine-wire signal.

This is in accordance with International Society of Electrophysiology and Kinesiology (ISEK) standards[403]. An adaptive cancellation algorithm was employed for those channels contaminated with ECG signal.

3.6.6.3 Video Recording

Synchronized digital video recording was performed during all EMG protocols with a video correction factor of 175 ms and 50 windows per second. EMG signals and videos were traced in real-time on the computer screen while the subjects performed the functional tasks.

3.6.6.4 Pre-Amplified Leeds

The first pre-amplified lead had three snaps and used to accommodate one bipolar dual snap surface electrode and a reference electrode with a single snap simultaneously. The other 15 pre-amplified leads had two-snap style and they were connected either to a bipolar dual snap surface electrode or a fine-wire adapter. The myoelectric signals were differentially amplified. The common mode rejection ratio of the amplifiers was >100 dB and the input impedance was >100 Mohm with a gain of 500 dB [Figure 3 – 14].

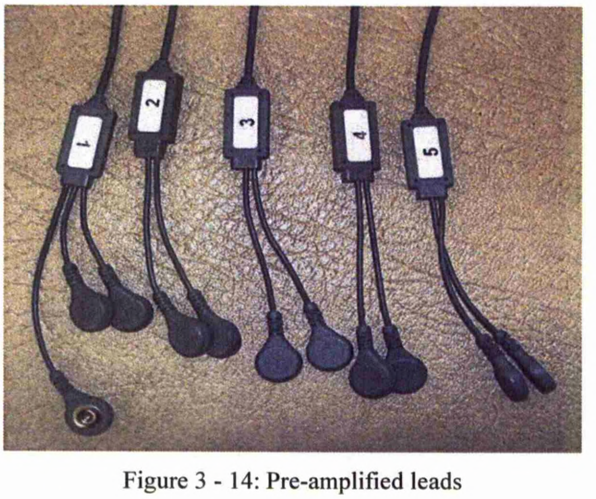


Figure 3 - 14: Pre-amplified leads

Lead No. 1 has three snap style connects to a surface electrode and a reference electrode simultaneously. Other leads have 2-snap style and connect to surface electrodes of fine-wire adaptors.

3.6.6.5 Electromyography Electrode Selection and Properties

Either surface or fine-wire electrode was used to record EMG signals from 15 shoulder girdle muscles as appropriate.

3.6.6.5.1 Surface Electromyography Electrodes

The surface electrodes were bipolar in configuration, 4 cm x 2.2 cm in size, figure-8 in shape, Ag/AgCl in composition and dual-snapped in style for their connection to pre-amplified leads with an inter-electrode distance of 2 cm (Noraxon, Arizona, USA). They were disposable, self-adhesive and pre-gelled. A single round electrode with similar specifications placed on the ipsilateral acromion was used as a reference electrode [Figure 3 - 15 A].

3.6.6.5.2 Fine-Wire Intramuscular Electromyography Electrodes

For deep intra-muscular recording, the fine-wire electrodes (44ga × 100 mm) with paired hook wires (CareFusion, USA) were used. In order to introduce the fine-wire electrodes into a deep muscle, a hypodermic needle (27ga x 30 mm or 25ga x 50 mm) was selected according to the depth of the studied muscle. At the distal end of the hypodermic needle, the paired hook wires could be seen in a length of 2 mm and 5mm. The first wire was stripped of insulation on the first 2 mm, while the second wire is insulated for the first 3 mm and stripped for the next 2 mm [Figure 3 – 15 B].

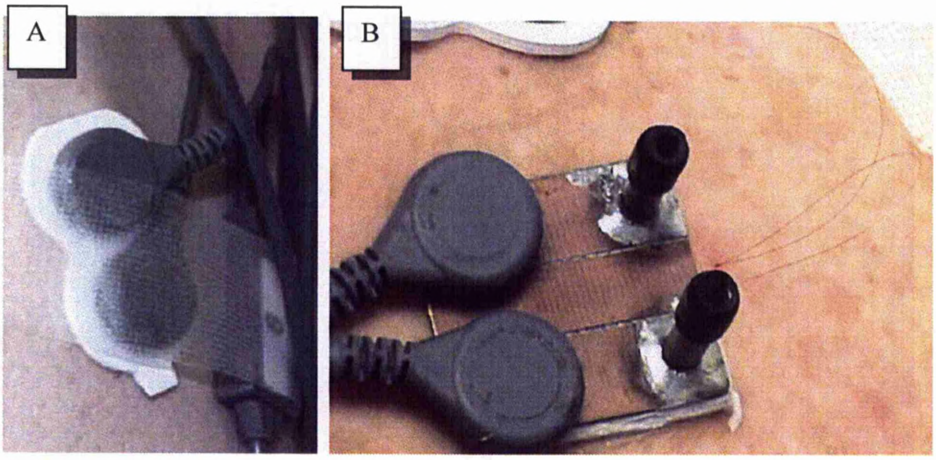


Figure 3 - 15: Secured electromyography electrodes.

(A) Surface electrode and (B) fine-wire intramuscular electrode anchored to adapter by springs

3.6.6.6 Electrodes Location and Placement

All electrodes were placed with participants in a sitting position which allowed appropriate identification of the target muscle and related anatomical landmarks. A skin marker pen was used to mark the thoracic spinous processes, shoulder girdle and borders of shoulder muscles. All requirements were shown in Figure 3 - 16.

3.6.6.6.1 Surface Electrodes

In order to achieve minimal skin impedance and proper electrode fixation, the skin over each selected muscle was shaved (if required), abraded with a skin gel (Nuprep), cleaned with alcohol and allowed to dry before placing the electrodes[434-437].

Figure 3 - 16: Items required for skin preparation and application of electrodes

(1) Razor, (2) Cotton wipe, (3) Cotton bud (4) Nuprep skin abrasive gel (5) Surface electrode with dual snap, (6) Reference electrode with single snap (7) Scissors (8) Alcohol wipes (9) Adhesive dressing (10) Anchored fine wire adapters (11) Skin marker (12) Sterile gloves (13) 30mm disposable hook wire electrodes, (14) 40mm disposable hook wire electrodes (15) Gauze (16) Transpore surgical tape, and(17) Alcohol hand wash

In principle, the surface electrodes were placed away from the edges of the muscle to avoid cross-talk, their orientation line should be parallel to muscle fibres to pick signal along their propagation, and approximately halfway between the innervations zone and the distal tendon[434]. The location of electrode placement for various muscles was determined based on standard guidelines provided in the literature [Table 3 - 3].

Table 3 - 3: Location of surface electrodes for shoulder muscle and relevant manual muscle tests

Muscle	Electrode placement	Manual muscle test
Anterior Deltoid (AD)	Feel lateral half of clavicle and deltoid tubercle. Electrodes placed on the anterior aspect of shoulder, 4 cm below the clavicle orientated in parallel to the muscle fibres towards deltoid tubercle.	Forward flexion and abduction of the shoulder against resistance.
Middle Deltoid (MD)	Feel lateral border of acromion and deltoid tubercle. Electrodes placed on the lateral aspects of shoulder 3 cm below the acromion, over muscle mass, and orientated in parallel to the muscle fibres.	Shoulder abduction against resistance
Posterior Deltoid (PD)	Feel lateral third of scapular spine. Electrodes placed 2 cm below the lateral border of the spine of the scapula and orientated obliquely towards the arm, to run in parallel to the muscle fibres	Shoulder abduction against resistance
Levator Scapulae (LS)	Shoulder actively raised while head and neck turned to opposite side. Feel lateral border of UT and LS just anterior to it. Electrodes placed on LS 2cm above supra-clavicular fossa and parallel to muscle fibres.	Shoulder elevation against resistance with the head and neck turned to opposite side
Upper Trapezius (UT)	Electrodes placed parallel to the muscle fibres along the ridge of the shoulder slightly lateral to the midpoint between C7 spinous process and acromion	Lift-up the shoulder against resistance (Shoulder shrug).
Lower Trapezius (LT)	Feel lower part of medial scapular border. Electrodes placed 5cm below scapular spine and just medial to medial scapular border, Orientation line placed oblique in 55° upward and laterally	With the arm flexed to about 90° shoulder girdle rotated downward and medially
Latissimus Dorsi (LD)	Electrodes placed 4 cm below tip of inferior angle of scapula	Simultaneous shoulder extension, internal rotation and adduction against resistance.
Teres Major (TM)	Electrode placed over the muscle belly, located immediately lateral to the lower one third of the lateral scapular border. Electrodes obliquely orientated, to run parallel to the muscle fibres.	Adduction, internal rotation and extension of the arm against resistance.
Serratus Anterior (SA)	Electrodes placed horizontally in the auxiliary area, mid-way between the xiphoid process and the inferior angle of the scapula.	90° shoulder and elbow flexion, shoulder protraction against elbow resistance
Pectoralis Major (PM)	Palpate for the clavicle. Electrodes placed on the chest wall at an oblique angle towards the clavicle, just medial to the axillary fold.	Resisted horizontal adduction with the shoulder and elbow flexed to 90°
Biceps Brachii (BB)	With elbow flexed against resistance and forearm supinated, feel muscle bulk. Electrode placed laterally on belly of long head, between the centre and distal tendon and parallel to muscle fibres	With the shoulder in neutral position, elbow flexed against resistance

3.6.6.6.2 Fine-Wire Electrodes

A sterile technique was used to insert the hypodermic needle with fine-wire electrodes deep into a muscle. A 30 mm 27 ga hypodermic needle was used for insertion of the wires into the SSP and ISP and RM. A 50 mm 25 ga needle was used for insertion of the wires into the SUBS. Following the removal of the needle, at least 6 specific isometric contractions for the tested muscle were performed to ensure the engagement of the hooked ends of wires into muscle fibres[438-440]. The specific location was guided by anatomical land-marks and confirmed by manual muscle tests [Table 3 - 4].

Table 3 - 4: Location of intra-muscular fine-wire electrodes and relevant manual muscle tests

Muscle	Electrode placement	Manual muscle test
Supraspinatus (SSP)	Hypodermic needle with fine wire electrodes inserted 1.5 cm above the mid-point of spine of scapula and deep to touch gently the scapula then pull out few millimetres.	60° abduction of arm in scapular plane and empty can position against resistance. Manual muscle test of UT to rule out miss-placement.
Infraspinatus (ISP)	Fine-wire electrodes inserted 2.5 cm below mid-point of spine of scapula and deep to touch gently the scapula then pull out few millimetres.	External rotation of the arm against resistance with the arm in 0° of abduction and 90° of elbow flexion. Manual muscle test of PD to rule out miss - placement.
Subscapularis (SUBS)	Full internal rotation of arm by placing the hand behind the back. Relaxation and internal rotation of scapula allowed backward prominence of scapular medial border. Fine-wire electrodes inserted just medial and anterior to scapular medial border at mid-point between inferior angle and root of scapular spine. The needle was directed gently 45° towards the head of the humerus.	Internal rotation of the arm against resistance with 0° of abduction and 90° of elbow flexion. Manual muscle test of SA and rhomboids to rule out miss-placement.
Rhomboid Major (RM)	The arm in neutral position. Fine-wire electrodes inserted mid-way between thoracic spinous process and medial border of scapula and levelled with mid-point between inferior scapular angle and root of scapular spine	Chest was supported. The test arm adducted against chest wall, the scapula adducted and elevated with elbow flexed fully and the shoulder slightly extended. Resistance was applied with one hand at elbow in the direction of abduction and the other hand at the shoulder in direction of depression

A 30 mm 27 ga hypodermic needle was used for insertion of the wires into the SSP and ISP and RM. A 50 mm 25 ga needle was used for insertion of the wires into the SUBS. Following the removal of the needle, at least 6 specific isometric contractions for the tested muscle were performed to ensure the engagement of the hooked ends of wires into muscle fibres[441,440].

3.6.7 Muscle Grouping and Rationale for Selection

Since Inman et al. (1944)[4], the notion of looking at muscles as functional groups rather than individuals with specific action based on their anatomical origins and insertions. According to the available facilities, we selected 15 important muscles around the shoulder girdle and GHJ to explore their myoelectric activity during dynamic cyclic tasks. The five axioscapular muscles (LS, UT, LT, SA and RM) are controlling the scapular position at rest and in motion. They allow the scapula to keep a rhythm of motion with the moving arm in any plane. Furthermore, we believe that coordinated onset and strategy of their activity provides stability of the scapula which allow the length-tension force generation in the next group. The humeral head centring muscle group includes the RC muscle (SSP, ISP and SUBS); LD, TM, PM and the long head of the BB. Although anatomically the muscles in this second group originated from the scapula to the humerus or chest wall to the humerus, their collective coactivated function is to maintain the head of the humerus centred in the glenoid at rest and during motion. Finally, the deltoid muscle with its components (AD, MD and PD) acts as a prime mover of the GHJ during forward elevation and lowering tasks.

3.6.8 Muscle Activation Patterns

The activation patterns of 15 shoulder muscles were tested during several cycles of movements that resemble daily life activities of shoulder rotations, forward reaching and overhead tasks[374,373]. A modified FIT-HaNSA protocol was used to collect EMG data during the functional movements in a cyclic pattern in order to develop averaged activation patterns 'ensemble average curves'[374].

3.6.8.1 Electromyography with a Modified Functional Impairment Test–Hand and Neck/Shoulder/Arm

The original FIT-HaNSA protocol[58,431] provides an appropriate system for assessing the functional capacity of upper extremity encompassing range of motion, power and endurance required for essential daily activities. Performing the tasks requires coordinated contributions from the majority of shoulder girdle muscles according to the given task by means of mobility and stability. Hence, a modified FIT-HaNSA test including three tasks was considered to provide an appropriate model for the EMG assessment of muscle activation patterns during dynamic and cyclic upper extremity movements. This modified protocol has been previously used in upper extremity pathologies with encouraging results. One of the main modifications was to add a new task which involved the internal and external rotation testing with similar principles to the other tasks in FIT-HaNSA[374]. A 5 minute rest period between the successive tasks ensured cumulative fatigue in the shoulder muscles did not develop. Considering the demands of the task, this was considered appropriate[431,374]. The shelving system used for modified FIT-HaNSA protocol has been previously described (Section 3.6.5.1) as originally implemented by MacDermid et al. (2007)[58].

3.6.8.2 Microphone Sensors

In order to provide a precise time definition during task performance a microphone sensor was applied, for the first time, to the under-surface of each shelf to pick real-time signals during the load contact with the shelves. Figure 3 - 17 shows the shelving system and embedded microphones into the shelves. The microphone analogue signals were transmitted to the PC through the TeleMyo mini-receiver and stored as digital data in Noraxon's MyoResearch XP software in association with EMG data. In addition, the microphone signals make easier synchronization of the video recordings with EMG signals.

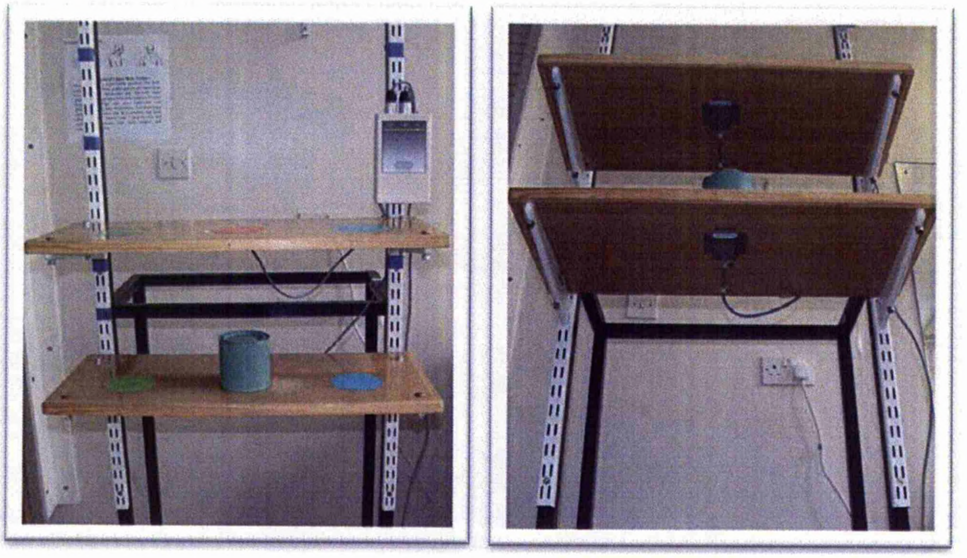


Figure 3 - 17: A modified shelving system for electromyography assessment.

3.6.8.3 First Task: Internal-External Rotation Task

The Internal-External Rotation Task (IERT) was used in healthy controls and SIS patients to assess and compare the activation pattern of rotator muscles of the shoulder. During the task, the arm remained in 0-15° of flexion and abduction and the hand moved in a horizontal plane.

The participants stood with their feet slightly apart and were instructed to keep the elbow tucked to the side during the movement. The shoulder was abducted and the elbow flexed to 90° with the fingers extended. The subject positioning was relative to the shelf so that the forearm was in line with the middle of the shelf, and the ulnar styloid levelled with front edge of the shelf.

This 2-phased task required internal- and external rotation of the shoulder. The participant was instructed to lift the weight above the shelf a small distance during each movement [Table 3 - 17]. The weight was held continually throughout the task. The pace of the movement was guided by a metronome set to 60 beats per minute: beat 1 indicated internal rotation with the weight lifted from one side of the shelf to the other (phase 1); beat 2 indicated external rotation with the weight returned to the starting position (phase 2). Phase 1 of the task involved internal rotation at the GH joint with elbow flexion. Controlled elbow extension placed the weight on the shelf at the halfway point in the cycle. Phase 2 of the task involved external rotation and the elbow was progressively extended until the weight was returned to the starting position. Modifications were made to the IERT following the pilot study, which are outlined where appropriate.

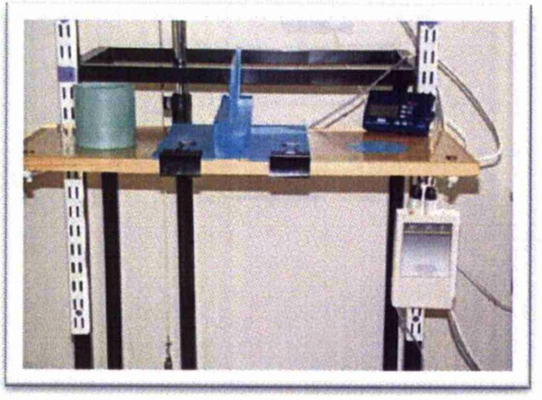


Figure 3 - 18: The shelving system for the internal-external rotation task.
A barrier was placed at the centre of the shelf to force the participant to lift the 1 kg container over it to the other side.

3.6.8.4 Second Task: Waist-Up Task

The WUT was developed by adapting and modifying task 1 from the FIT-HaNSA protocol[58]. A single 1 kg weight, under the guidance of a metronome set a 60 bpm, was lifted from the lower shelf, to the upper shelf and back. The lower shelf was set at the level of the participant's waist and the upper shelf 25 cm above. The participant was positioned relative to the shelves in accordance with guidelines of the Tasks 1 and 2 of the FIT-HaNSA test[58] [Table 3 – 5].

Phase 1 of the WUT involved lifting the weight from the lower to the higher shelf and phase 2 involved returning the weight from the higher to the lower shelf. Phase 1 followed by phase 2 together represented one cycle. The coloured markers on the shelf guided the motion path and the positioning of the weights on each shelf [431,374] [Table 3 – 5].

Phase 1 of the task predominantly involved a combination of forward flexion and abduction at the shoulder, with the goal of reaching and placing an object on a shelf. Phase 2 of the task involved a degree of extension and adduction at the shoulder assisted by the gravity. In order to initiate movement and place the weight on the shelf, both phases began, and to a lesser degree finished, with elbow flexion and extension, respectively. The task operated within the functional range of the shoulder and was directly relevant to activities of daily living, such as reaching for an object.

3.6.8.5 Third Task: Eye-Down Task

The EDT was developed by modifying task 2 from the FIT-HaNSA protocol[58]. One shelf was set at the participant's eye level and a second shelf placed 25cm below. The participants were positioned as for the WUT. A single 1 kg weight was lifted from the lower to the higher shelf and returned, under the same constraints as for the WUT. Following completion of the EDT the participants rested for 5 minutes[442] [Table 3 - 2].

The motion path during this task was the same as for the WUT. However, with the shelf set at a higher level, a greater degree of GH flexion and abduction as well as scapular elevation was required. It was a challenge for the SIS patients and positive painful arc test. Again, this task was an appropriate representation of a number of daily activities.

Table 3 - 5: Summary of tasks for muscle activation pattern assessment.

Task and Rest	Lower Shelf Position	Higher shelf position	Action	Guide	Duration
First task: 'Internal-external rotation task'	Forearm level with the elbow 90° flexed	No	Lifting 1 kg container above the shelf from external position to internal one and back.	Metronome set to 60 beats/minute Coloured spots on the shelf.	60 seconds
Rest			Relax		5 minutes
Second task: 'Waist up task'	Waist level	25 cm above the lower shelf	Lifting 1 kg container from lower to higher shelf and return	Metronome set to 60 beats/minute Coloured spots on shelves	60 seconds
Rest			Relax		5 minutes
Third task: 'Eye-down task'	25 cm below the higher shelf	Eye-level	Lifting 3 weights from lower to higher shelf and return	Metronome set to 60 beats/min. Coloured spots on shelves	60 seconds

3.6.9 Signal Recording

The EMG signals from 15 muscles and synchronised video (25 frames/s; 50 fields/s) were recorded during each task. The video was recorded by handy-cam Panasonic video connected to the computer by means of a USB cable. Each task was performed for 1 minute, or until the patient could no longer continue. Ideally, at least 10 complete cycles were recorded.

Additionally, a 20-30 second period of signal was recorded while each participant was completely relaxed; this period of signal facilitated ECG removal and signal check procedures.

3.6.10 Signal Check Procedures

A number of signal check procedures were performed according to available guidelines. Each channel was inspected individually to ensure the background noise does not exceed 10-15 μV. Each signal was also inspected for baseline offset, a shift in the signal away from the true zero line. Finally a power spectrum was calculated and checked to ensure a steep increase from the high pass; a peak frequency between 50-80 Hz for surface electrodes and 75-140 Hz for fine wire electrodes; a steady decrease thereafter and no evidence of interfering power hum. Signals of poor quality were excluded from the data analysis.

3.6.11 Off-Line Signal Processing and Analysis

Assessment of muscular effort requires analysis of the amplitude of the detected signal. A number of signal processing steps were required. The signal processing and data handling is described in detail in the following sections.

3.6.11.1 Electromyographic Signal Filtering:

The signals recorded via surface electrodes were band-pass filtered; low frequency cut off 10Hz, high frequency cut off 500Hz (Filter type: Finite Impulse Response Filter; Window: 79 points; Window edge fading: none). The fine wire signals were high-pass filtered (10 Hz) with a Butterworth filter. Filter setting followed both international guidelines and manufacturer recommendations [Figure 3 - 19].

3.6.11.2 Electrocardiograph Reduction

MyoResearch XP possesses a preconfigured ECG reduction algorithm. The signals recorded during the rest period were individually inspected; the ECG reduction algorithm was applied to any channel with evidence of an ECG spike above the background noise. An area of signal with at least 3 ECG spikes visible above the baseline was marked; the algorithm uses a combination of pattern recognition and adaptive filtering to remove the ECG spikes while not affecting the power of the underlying signal.

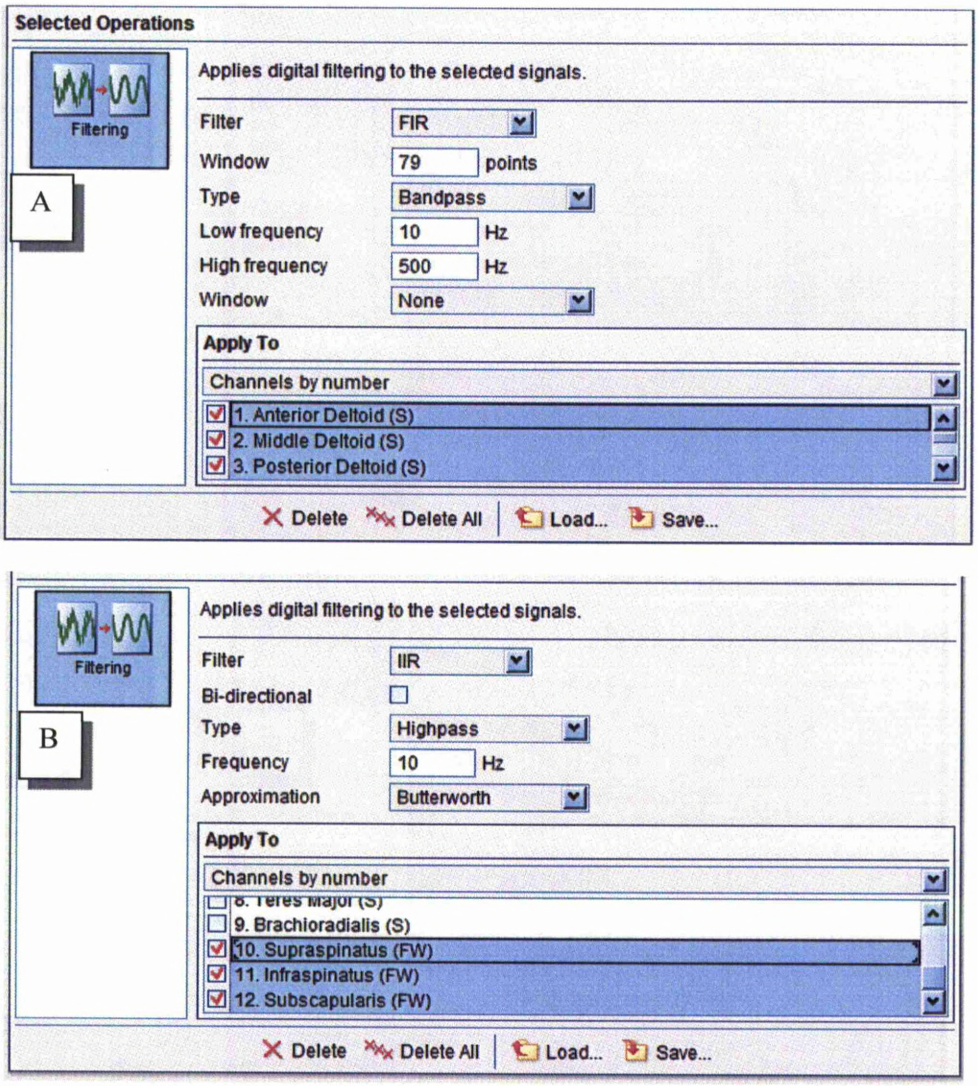


Figure 3 - 19: Signal processing (1) filter setting.

(A) Filtering for surface electrodes and (B) filtering for fine-wire electrodes

3.6.11.3 Rectification

Full wave rectification of the signals was performed, followed by smoothing using an RMS algorithm (window of 100 ms). A time window of 100 ms was appropriate given the nature of the movements involved in the protocol (Noraxon). Each frame represented 20 ms. Ideally, the first 5 cycles were ignored to ensure the subject was familiar and comfortable with the movement.

3.6.11.4 Normalization

Normalization was performed to provide comparable information about inter- and intramuscular activity as well as interpersonal comparisons.

3.6.11.4.1 Amplitude Normalization

Allison, Marshall and Singer reported the effect of 11 amplitude normalization techniques on the coefficient of variation (CV) during the eccentric and concentric phases of stretch-shortening cycles (SSC).

The EMG amplitude normalization using the isometric MVC in a defined position is a common method. It is recommended to use the maximum of rectified and filtered EMG of an MVC for normalization and to express the resulting EMG level as a percentage of MVC. However, using the mean or peak of each phase as a reference value is recommended to be more appropriate for normalization of EMG amplitude in dynamic and phasic movements[345,374]. Hence, amplitude normalisation was performed relative to the mean for EMG recordings collected during dynamic tasks aimed to investigate muscle activation patterns.

3.6.11.4.2Time Normalization

In case of cyclic movements, time normalization may be necessary. EMG is expressed in relation to the percentage of cycle or phase. To do so, time information of the original EMG is lost and is not reproducible.

3.6.12 Ensemble Average Curves

A predefined analysis option is available in MyoResearch XP software for production of ensemble average curves, or 'Average Activation Profile' for different phases of the movement. The phases of movement were manually defined by placing markers in the EMG signals guided by the synchronised signals of the microphone sensors and video. The first marker was placed at the first contact of the load on the lower shelf and the second marker at the first contact with the higher shelf. A third marker was placed when the load contact the lower shelf again and represented the end of the first cycle and the beginning of the second. Marker placement demanded a frame by frame analysis of the recorded signal and ensured synchronization between EMG signals, microphone signals and video. The synchronised video was captured at 50 frames per second.

The averaged activation curves were developed for all individual muscles during each muscle task from an average of 10 cycles and exported to Microsoft Excel as numerical values for further analysis. Each average cycle was divided into phase 1 and phase 2, of each the mean amplitude was calculated. For the purpose of data reduction, the mean amplitude was calculated for every 5% interval of the average cycle leadings to 10 mean amplitude values in phase 1 and 10 mean amplitude values in phase 2. These values were used for statistical comparison of average activation curves.

The duration of the average cycle in total, phase 1 (first shelf contact time + off-shelf time) and phase 2 (second shelf contact time + off-shelf time) were calculated from absolute time scale of the EMG recording.

3.6.13 Qualitative Assessment of Muscle Activation

Taking in consideration the normalization of data and aiming to a simplified visual descriptive technique which displays relative comparisons between 15 muscles with 3 different colours at each time point (each 5% interval). The 15 mean amplitude % for the 15 muscles at a single 5% interval were sorted from maximum to minimum. The highest 5, middle 5 and lowest 5 values were ranked as 'high, moderate and low' relative muscle activity, respectively. A diagram with the representative colour ranks was presented to reflect muscle behaviour individually and in a group.

3.7 Muscle Fatigue during Sub-Maximal Voluntary Contraction

This protocol aimed to measure and compare the fatigability of 15 shoulder girdle muscles in healthy controls and SIS patients during 4 distinct shoulder movements as used for strength measurements (forward flexion, abduction, internal and external rotations - section 3.6.3) while performing a submaximal voluntary contraction. In order to minimise the impact of pain experience on the measurements a 25% of isometric MVC was thought to provide an appropriate submaximal force exertion for the fatigue measurement. The purpose of the test was to assess and compare the shoulder muscle maximum activation level during 5 seconds of isometric MVC.

3.7.1 Equipment (Electromyography System/Mecmesin Myometer)

EMG system, Shoulder Mecmesin Myometer, and PC were required for this measurement. While the EMG electrodes still in place and connected to the transmitter and software, the subject used the Mecmesin myometer (section 3.6.3) to perform required submaximal isometric MVC of studied movements by the feedback provided on the PC screen.

3.7.2 Position

Subjects were seated in upright position on a chair and the tested upper limb in the recommended position for each movement of the four standard shoulder movements as described in section 3.6.3. The strap of the myometer was usually applied to the wrist.

3.7.3 Protocol

The dominant or non-dominant arm in healthy controls and the affected arm in patients were tested for muscle fatigue. These initial strength tests provided the isometric MVC value for shoulder flexors, abductors, internal and external rotators. It is also expected that the majority of shoulder gridle muscles are activated during these movements, however at various levels. Hence, these values were used to calculate 25% of MVIC. After familiarization with the test, participants were instructed to insert a steady force at desired submaximal level for 60 second with a real time feedback provided by the Lite software (Mecmesin Myometer) on a PC screen. This experiment The EMG signals reflected the extent of muscle fatigue during 60 seconds of 25% isometric MVC.

3.7.4 Data Management and Fatigue Indices

After standard signal processing, predefined programs were performed through MyoReasearch XP software for the calculation of MdF (Fast Fourier Transformation for power spectrum analysis) as an important index for quantifying muscle fatigue. The MdF was calculated for 1 second intervals and normalised to the average of the first two values[133]. The rate of change of the normalised MdF was determined using the LINEST function in Microsoft Excel 2010. LINEST utilises the least squares method to calculate a straight line that best fitted the data, and returns a statistic that best describes the line. This statistic described the rate of change of the MdF over time (slope). The value was expressed as percentage change per minute (%/min) and used as the fatigue index (Slope %/min) in this study.

3.8 Data Analysis

3.8.1 Clinical Assessment Analysis (Non-Electromyography Data)

Descriptive statistics for strength, range of motion, postural measurements, functional performance and self-report questionnaires (dependent variables) were calculated. The majority of skewness and normality tests were in favour of non-parametric statistical tests. The independent factors were gender (females and males), participants (patients and controls) and male ethnic groups (Caucasians and Non-Caucasians). Two-independent statistical tests were applied through the whole data set. Paired *t*-tests were used to evaluate the dominant and non-dominant sides in controls. The dependent variables included: muscle strength, ROM, bilateral and axial measurements, FIT-HaNSA and self-reporting questionnaires. An alpha level of 0.05 was used for all tests. All statistical analyses were conducted with SPSS (18.0 for Windows, Chicago, Il, USA).

3.8.2 Electromyography: Data Management and Analysis

3.8.2.1 Cycle Duration

The mean duration of shelf-contact and off-shelf (seconds) for phase 1 and phase 2 of each functional task (IERT, WUT, and EDT) will be reported and compared within Female and Male groups of SIS patients and controls.

3.8.2.2 Mean Amplitude (Muscle Activation Patterns)

The mean normalized amplitude (AMP) for phase 1 and phase 2 of functional tasks (IERT, WUT, and EDT) is reported and compared amongst 15 individual studied muscles comprising SP (scapular), HHC (humeral head centring) and Deltoid muscle groups in Female and Male groups of SIS patients and controls.

The normalized duration of the averaged cycle (time %) during each task is further divided into 20 intervals (5% each) and the average of mean AMP % will be calculated for each interval (a total of 20 intervals). The normalized mean AMP values of these intervals are used for the presentation and comparison of activation patterns in three major muscle groups (SP, HHC, Deltoids) as well as individual muscles contributing to each group in Female and Male groups of SIS patients and controls.

The activation patterns of 15 individual muscles and three major muscle groups will also be demonstrated graphically during IERT, WUT, and EDT mainly using ensemble-averaged curves in female and male groups of SIS patients and controls.

Finally, a qualitative assessment of muscle activation patterns will be provided in tandem with the level of contribution from each individual muscle to associated muscle group. To do this, the mean AMP % of each individual muscle will be categorised at each interval of the time domain from maximum to minimum values and ranked to 'high, moderate or low activity' for the first five high values, second five values and last lower five values. *(A flow chart for the EMG data management is also presented at the beginning of Chapter 6).*

3.8.2.3 Median Frequency (Muscle Fatigue)

Normalized MdF mean values over 1-second intervals will be used to calculate a Fatigue index (MdF Slope%/min) representing the rate of changes of MdF over the duration of fatiguing tasks.

The fatigue index will be used to report and compare the fatigability of individual muscles of 3 major muscle groups during the experiments (25% MVC of forward flexion, abduction, external and internal rotation in female and male groups of SIS patients and controls. A few sample graphs of MdF changes over time during the fatiguing task will be presented.

Descriptive statistics will be used to present the key mean values, standard deviation or standard error of measurement as appropriate. A number of statistical tests were considered for testing the significant differences between study groups. In order to apply the appropriate statistical analysis a combination of normality tests including the normal probability plots, Shaprio-Wilk, and skewness coefficient assumptions were used to investigate the distribution of the data. Following normality tests, non-parametric test were chosen appropriate for the final analysing of data. Two-related Samples Tests (Wilcoxon) and Two-independent Samples Tests (Mann-Whitney) were used for intra-group and inter-group analysis and comparisons, respectively. For all tests, significance level was set to 0.05. SPSS (PASW statistics 18 for Windows) was used for statistical analysis.

4 CHAPTER FOUR: PARTICIPANTS

Seventy-three volunteers took part in this study; 34 healthy controls (CG) and 39 patients with a diagnosis of SIS who satisfied the inclusion criteria (PG). SIS spares neither male nor female, presents as a painful problem in either shoulder regardless of the side of the dominant hand and is observed in all ethnic groups. Whether these characteristics altered normal shoulder function in the performance of the tests we proposed to use was unclear. The first series of analyses aimed to answer this question.

4.1 Control Group (n=34)

With the potential for gender, ethnic group and handedness, to influence shoulder function through differences in strength, laxity and customary shoulder usage, it was vital to clarify the integrity of the control group with respect to characteristics, which would be evident in the PG.

Objectives:

1. To identify any significant gender, ethnicity and handedness differences within the control group
2. To establish appropriate group specific clinical data of shoulders of healthy volunteers

None of the healthy volunteers experienced any difficulty in performing all the clinical tests for shoulder pathologies perfectly, indicating an absence of shoulder problems. Data from the systematic measurements of muscle strength, ROM, bilateral and axial postural measurements, FIT-HaNSA and self-reporting questionnaires was collected and divided into the following subgroups for analysis: (1) female or male; (2) Caucasian or Non-Caucasians; (3) dominant or non-dominant. Some measures are on a variable scale, while others reach a plateau maximum of 100%. Thus a problem was encountered in evaluating the data when for example all controls had a maximal score of 100% and no standard deviation was calculable, beyond that, occasionally one control would be deficient in 1% generating an artificial idea of significance. Such problems have been documented below. The raw data is presented in chapter 5 where it is tabulated in comparison to patient data. Thus the 34 healthy volunteers of the control group included 13 females and 21 male. All female participants were Caucasians while of the male participants eight were Caucasians and 12 were non-Caucasians. The non-Caucasian male subgroup included 11 Arabs and one Indian in nationality. Handedness differences were investigated by performing all clinical assessments and measurements bilaterally when possible i.e. not axial measures. Two male volunteers had mild, sporadic pain during the last 4 weeks preceding their involvement but there were no other clinical findings and hence no evidence of any shoulder pathology. EMG assessments were applied unilaterally to 22 dominant shoulders and 11 non-dominant shoulders in the healthy volunteers although one participant could not attend the EMG session.

4.1.1 Establishing the Validity of the Control Group(s)

The demographic data is presented in Table 4 – 1 and Appendix III. In order to compare the data, non-parametric statistical tests were used and relevant *p* values were given in Table 4 - 2.

Table 4 - 1: A summary of the demographic data, including age, height, body weight and body mass index (BMI), of control group.

Control Group	Descriptive	Age (years)	Height (cm)	Body weight (Kg)	BMI (Kg/m^2)
Female(n=13)	Mean	42.9	168.4	69.1	24.3
	SD	9.3	7.0	8.6	2.3
	Range	28-54	158-182	50-82	18.8-28.3
Male (n=21)	Mean	47.6	172.4	76.8	25.8
	SD	10.3	10.0	12.6	3.2
	Range	28-68	156-191	62-120	20.5-32.9
All (n=34)	Mean	45.8	170.9	73.9	25.2
	SD	10.0	9.0	11.7	2.9
	Range	28-68	156-191	50-120	18.8-32.9

4.1.2 Handedness (Dominant versus Non-Dominant)

No significant differences, using non-parametric 2-related tests, were found in the tests applied to dominant and non-dominant shoulders, either when compared as 'all controls: dominant vs. non-dominant', or when compared within gender subgroups. Female controls did not differ in the muscle strength between dominant and non-dominant shoulders except in the flexor muscles and the same pattern was observed in male controls. Female and male controls did not show any difference in the ROM between the dominant and non-dominant shoulders.

4.1.3 Ethnic Groups (Caucasians versus Non-Caucasians)

The muscle strength, axial postural measurements, FIT-HaNSA, CMS, self-reported function and quality of health did not differ (showed similar mean results) in both Caucasians and non-Caucasians male controls [Table 4-1]. The significant difference only detected in flexion and external rotation ROM as well as in lateral scapular sliding test at rest (LSSTP1) [Table 4 – 2]

4.1.4 Gender

Isometric MVC: Generally female controls experience less muscle force in the shoulder than the male controls. A gradual increase in the shoulder muscle force was observed in the controls of both sexes with an ascending pattern from the abductors, flexors, external rotators to the internal rotators, which had the maximal muscle force. The muscle strength between female and male controls in both dominant and non-dominant shoulders showed a significant difference (p<0.01).

ROM: shoulder ROM of female controls in all directions was greater than male controls. Internal rotation was assessed using the score in Constant and Murley, and showed no difference. The ROM did not vary significantly in the dominant shoulder of controls between both sexes, but in the non-dominant shoulder it showed a significant difference in the flexion, extension, abduction and adduction (p<0.01).

Table 4 - 2: Comparative summaries of statistical differences between sexes, ethnic groups and handedness for isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements, functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA) and self-reporting questionnaires. Bold p values are less than 0.05.

	Controls				
	Female (13) vs. Male (21)	Caucasian (8) vs. Non-Caucas.(13)	Dom. vs. Non-dom.		
			All	Female	Male
Isometric MVC (N)					
Flexors	**0.00**	0.76	0.32	0.09	0.27
Abductors	**0.00**	0.99	0.76	0.33	0.79
External Rotators	**0.00**	0.29	0.90	0.88	0.69
Internal Rotators	**0.00**	0.13	0.16	0.59	0.11
ROM (°)					
Flexion	**0.02**	**0.05**	1.00	1.00	1.00
Extension	**0.02**	0.50	0.42	0.43	0.61
Abduction	**0.05**	0.47	0.97	1.00	0.95
Horiz. Adduction	**0.00**	0.55	1.00	1.00	1.00
External Rotation	**0.00**	**0.02**	0.29	0.23	0.46
Internal Rotation*	**0.03**	0.07	0.23	1.00	0.22
Bilateral posture					
NSP (%)	0.54	0.31	0.68	0.27	0.84
SI (%)	0.56	0.95	0.91	0.86	0.87
LSST 1 (cm.)	**0.03**	**0.00**	0.88	0.70	0.61
LSST 2 (cm.)	0.53	0.30	0.96	0.72	0.90
LSST 3(cm.)	0.17	0.69	0.87	0.09	0.27
Axial posture					
TKI (%)	**0.02**	0.69			
FHP (°)	0.30	0.36			
FSP (°)	**0.02**	0.51			
FIT-HaNSA					
WUT (%)	1.00	1.00	1.00	0.88	0.89
EDT (%	0.20	0.77	0.95	1.00	1.00
OHT (%)	0.25	0.69	0.62	0.83	0.39
Average	0.16	0.82	0.85	0.56	0.57
Questionnaires					
CMS	**0.00**	0.97	0.99	0.65	0.12
OSS	**0.02**	0.96			
DASH	0.36	0.94			
DASH_Op1	0.30	0.37			
DASH_Op2	0.49	0.09			
ULFI	0.11	0.86			
GHSF12	0.41	0.98			
GHSF12_PC	0.57	0.71			
GHSF12_MC	0.10	0.82			
HADS	0.22	**0.01**			
HADS_AC	0.25	**0.02**			
HADS_MC	0.06	**0.02**			
MPQ	**0.04**	0.65			

* The mean presented as the score used in CMS

Posture: The bilateral postural measurements were similar in controls of both sexes, but the axial postural measurements were higher in males than female controls except in the FHP. The bilateral postural measurements did not significantly differ in the dominant and non-dominant shoulders of controls between both sexes [Table 4 – 2]. The axial postural measurements of TKI and FSP showed a significant difference in controls of both sexes ($p<0.05$). Female controls showed more thoracic kyphosis, more FHP and less FSP than male controls. The bilateral postural measurements showed some differences in the female controls between dominant and non-dominant shoulders but in male controls there was no difference.

FIT-HANSA The functional performance of FIT-HaNSA, in both male and female controls showed similar functional performance either in using the dominant or non-dominant shoulder. The FIT-HaNSA did not show any difference between dominant and non-dominant shoulders of both female and male controls. The CMS breakdown of individual domains was not different between both shoulders in either females or males [Table 4 – 2].

Questionnaires: self-reporting function and quality of health did not differ among controls of both sexes but the scores of CMS were higher in male controls than female controls [Table 4 – 2]. Although the total CMS showed significant difference in the dominant and non-dominant shoulder between controls of both sexes but the results of individual domains were not significantly different except in the power domain ($p<0.001$). The scores of other self-reporting function and quality of health were within the normal range in controls of both sexes and did not show any significant difference.

In summary, the statistical differences were not existing between the dominant and non-dominant sides and minimally significant in few tasks between ethnic groups, but highly significant in most of the tested measures between female and male healthy volunteers. Therefore, the control participants were grouped according to gender [Figure 4 – 1].

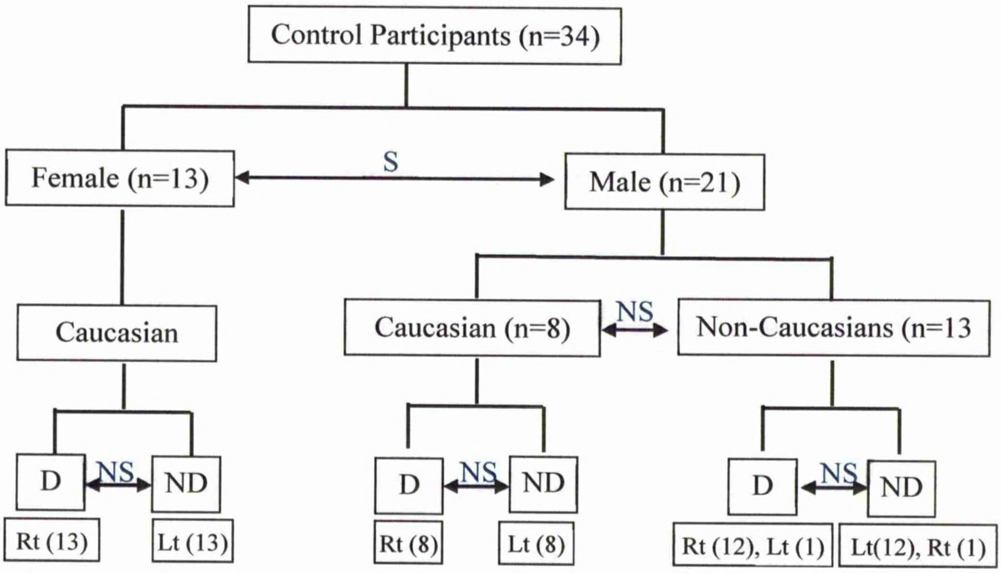


Figure 4 - 1: Final groups of control participants.

S indicates a statistically significant difference between the two groups, while NS indicates no significant difference. D is the dominant hand and ND is the non-dominant hand. Rt represents the right hand and Lt the left hand.

4.2 Patient Group

The patients group (PG) was composed of 39 patients (20 female and 19 male patients). All patients were Caucasians with the exception of 1 female and 1 male who were both non-Caucasians. All clinical assessments were performed on the affected and unaffected shoulders as far as applicable, while EMG recordings were applied to the affected shoulders. Handedness and ethnicity were not included as relevant factors for analysis as the control groups showed minimal or no differences. However, as gender was a significant factor in the control group, all patients' data was presented as female, male or combined. The demographic data was summarised in Table 4 – 3 and Appendix III.

Table 4 - 3: A summary of the demographic data, including age, height, body weight and body mass index (BMI), of patient group.

Control Group	Descriptive	Age	Height	Body weight	BMI
	Mean	55.5	161.3	78.0	29.9
Female patients	SD	5.3	7.1	15.6	5.3
	Range	46-64	152-147	55-117	21-42
	Mean	54.2	173.8	83.6	27.6
Male patients	SD	8.1	9.7	11.7	2.6
	Range	33-72	152-186	58-105	22-32
	Mean	54.9	167.4	80.7	28.8
All patients	SD	6.7	10.5	13.9	4.3
	Range	33-72	152-186	55-118	21-42

4.2.1 Establishing Subacromial Impingement as the Primary Pathology in the Patient Group

Patients were recruited to this study following a diagnosis of impingement syndrome and before definitive treatment. The study process takes a little time and that combined with the knowledge that additional information on shoulder integrity would become apparent following final reports from imaging and from intra-operative findings, it was necessary to undertake the study and adjust the groupings of the patients in the light of such information. All patients underwent a thorough shoulder examination including a series of typical clinical tests. Some tests were too painful for some patients and they have been listed below. All patients demonstrated patterns of response indicative of SIS but not of GHJ instability or rotator cuff tears. However, some patients demonstrated the possibility of a more complex pathology and some patients had SIS problems in both shoulders, although one was worse than the other.

Table 4 - 4: The clinical tests used in this study and the number of positive and negative cases for each test.

Clinical Tests	Female Patients with Impingement (n=21 shoulders)		Female improved Patients (n=4 shoulder)		Male Patients with Impingement (n=26 shoulders)	
	Positive	Negative	Positive	Negative	Positive	Negative
Painful arc*	18	1		4	20	3
Neer's sign*	16	3		4	18	5
Hawkin's sign	17	4	3	1	21	5
Drop arm*	1	18		4	4	19
Resisted external rotation	4	17		4	6	20
Resisted internal rotation	2	19		4	9	17
Lift off *	8	13		4	16	10
full can	11	10	0	4	12	14
Empty can*	13	6	2	2	16	7
Belly-press	1	20		4	2	24
Inferior sulcus	0	21		4	1	25
Apprehension*	1	18		4	4	19
O'Brien*	4	17		4	6	20
Speed's	3	18		4	5	21

* Two female and three male patients were not tested because of increased pain

Thus following final data assimilation, clinical tests [Table 4 – 4], medical records, ultrasound and intra-operative observations, the clinical assessment and measurements revealed 3 clinical subgroups in both genders. In the female group, there were 11 patients with unilateral impingement and 5 with bilateral. In addition, four female patients had attended 3-10 weeks of physiotherapy treatment. Amongst the males, there were 6 patients with unilateral, 7 with bilateral and 6 with a complex pathology. The last 6 male patients were having unilateral impingement plus partial RC tear (2), SLAP lesion (2), partial tear of the long head of biceps (1) and tendinitis of long-head of biceps (1). Those with additional pathology were grouped as 'unilateral impingement plus (UIMPP)' [Figure 3- 1].

4.2.2 Validation of Patient Groups

Using the clinical measurements and scores obtained from muscle strength, ROM, posture, functional impairment test and self-reporting questionnaires, the objectives were:

1. To establish whether the affected shoulder in patients in whom impingement syndrome presented itself in isolation (unilateral) was significantly different from their other unaffected shoulder, regardless of gender.
2. To establish whether the affected shoulders in patients in whom impingement syndrome presented bilaterally were significantly different from each other or from unilateral affected or unilateral unaffected shoulders of the same gender.
3. To establish whether the affected shoulders in patients in whom impingement syndrome presented as part of a more complex shoulder pathology were significantly different from each other or from unilateral affected or unilateral unaffected shoulders of the same gender.
4. To establish a valid set of gender specific and gender non-specific data on SIS shoulders which would support comparison with the appropriate control group of data.

Raw data: all female and male patients raw data was presented in Appendix IV. Having validated group inclusion, the results of female and male impingement shoulders and comparisons with controls were presented in 'Chapter Five'.

Table 4 - 5: Comparative summaries of statistical differences between the unilateral affected and unaffected shoulders in female and male patients for isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements and Constant-Murley score (CMS). Bold p values are less than 0.05.

Tasks		Unilateral Affected vs. Unaffected Shoulders	
		Female Patients (n=11)	Male Patients (n=12)
Isometric MVC (N)	Flexors	**0.00**	**0.03**
	Abductors	**0.00**	**0.01**
	External Rotators	**0.02**	**0.05**
	Internal Rotators	**0.05**	**0.03**
ROM (°)	Flexion	**0.00**	**0.02**
	Extension	**0.00**	**0.02**
	Abduction	**0.00**	**0.00**
	Horiz. Adduction	0.08	**0.02**
	External Rotation	0.03	**0.04**
	Internal Rotation*	**0.00**	**0.00**
Bilateral Posture	NSP (%)	0.53	0.60
	SI (%)	0.67	0.49
	LSST 1 (cm.)	0.53	0.91
	LSST 2 (cm.)	0.39	0.25
	LSST 3(cm.)	0.25	0.09
Questionnaire	CMS	**0.00**	**0.00**

* The mean presented as the score used in CMS

Female patients: The differences between the affected and unaffected shoulders of 11 female patients with unilateral impingement demonstrated significant weakness in flexion, abduction, external and internal rotation and reduced range of motion in flexion, extension, abduction and internal rotation [Table 4-5]. This gave two comparator data sets against which all other female shoulder groups could be aligned accordingly.

Table 4 - 6: Comparative summaries of statistical differences between patients with unilateral impingement (UIMP) (affected and unaffected) vs. bilateral impingement (BIMP) (more affected and less affected) and UIMP improved (affected and unaffected) shoulders.
The comparison was in respect of isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements, functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA) and self-reporting questionnaires. Bold *p* values are less than 0.05.

Tests	Female Patients (n=20)					
	UIMP affected shoulders (n=11) vs.			UIMP unaffected shoulder (n=11) vs.		
	BIMP more affected (n=5)	BIMP less affected (n=5)	UIMP improved affected (n=4)	BIMP more affected (n=5)	BIMP less affected (n=5)	UIMP improved affected (n=4)
Isometric MVC(N)						
Flexors	0.06	0.78	0.36	**0.00**	**0.00**	**0.02**
Abductors	0.23	0.87	0.06	**0.00**	**0.01**	0.12
External Rotators	0.40	0.78	0.15	**0.00**	**0.03**	0.79
Internal Rotators	0.10	0.53	0.43	**0.00**	**0.04**	0.36
ROM (°)						
Flexion	0.95	0.23	**0.01**	**0.00**	0.14	0.52
Extension	0.95	0.06	**0.00**	**0.02**	0.43	**0.01**
Abduction	0.73	0.23	**0.00**	**0.00**	0.06	**0.05**
Horiz. Adduction	0.60	0.91	0.68	0.06	0.10	0.15
External Rotation	0.34	0.49	0.22	**0.01**	0.3	0.59
Internal Rotation*	0.33	0.04	**0.01**	**0.01**	0.53	0.45
Bilateral posture						
NSP (%)	0.87	0.46	0.70	0.95	0.87	0.70
SI (%)	0.87	0.61	0.15	0.78	0.69	0.19
LSST 1 (cm.)	0.78	0.95	0.84	0.53	0.65	0.70
LSST 2 (cm.)	0.61	0.91	0.70	0.21	0.50	0.36
LSST 3(cm.)	0.50	0.73	0.90	0.10	0.14	0.51
Axial Posture						
TKI (%)	0.79		0.19			
FHP (°)	0.28		0.12			
FSP (°)	0.83		**0.02**			
FIT-Hans						
WUT (%)	0.35	0.64	0.07	**0.02**	0.22	0.40
EDT (%	0.14	0.08	**0.02**	**0.05**	0.13	0.06
OHT (%)	**0.03**	0.58	**0.05**	**0.02**	0.07	0.20
Average	0.09	0.52	**0.02**	**0.01**	0.12	0.14
Questionnaires						
CMS	0.95	0.13	**0.00**	**0.00**	**0.00**	0.21
OSS	0.12		**0.01**			
DASH	0.15		**0.00**			
DASH_Op1	0.20		0.75			
DASH_Op2	0.18		0.49			
ULFI	0.07		0.23			
GHSF12	**0.04**		0.19			
GHSF12_PC	0.12		0.13			
GHSF12_MC	**0.02**		0.17			
HADS	0.09		0.12			
HADS_AC	0.26		0.11			
HADS_MC	0.08		0.32			
MPQ	0.40		0.21			

* The mean presented as the score used in CMS

The data demonstrated that both bilateral impingement shoulders were comparable to the affected unilateral and different from the unaffected shoulder. Those patients in receipt of initial physiotherapy to their affected shoulders demonstrated significant differences from the affected and unaffected unilateral shoulders. These latter patients did not conform to our criteria and have significantly different shoulders.

Male patient: As only six male patients had uncomplicated UIMP, the order of comparisons was difficult. The first question was whether those unilateral shoulders with a more complex pathology (UIMPlus) were most comparable to UIMP affected or unaffected or different from both. The data demonstrated greater measures of significant difference from the unaffected shoulder and hence all unilateral shoulders were pooled regardless of the additional pathology. Next, we determined whether as in the female patients both the male bilateral shoulders could be pooled with unilateral shoulders [Table 4 – 7].

Table 4 - 7: A comparative summary of statistical differences between unilaterally affected then unaffected shoulders vs. affected shoulders in male patients with bilateral and complex impingement. The comparison was in respect of isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements, functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA) and self-reporting questionnaires. Bold *p* values are less than 0.05.

Tests	Male Patients(n=19)					
	UIMP affected shoulder (n=6)			UIMP unaffected shoulder (n=6)		
	BIMP more affected (n=7)	BIMP less affected (n=7)	UIMP plus affected (n=6)	BIMP more affected (n=7)	BIMP less affected (n=7)	UIMP plus affected (n=6)
Isometric MVC (N)						
Flexors	0.20	0.32	0.27	**0.01**	0.06	0.06
Abductors	0.32	1.00	0.86	**0.03**	0.09	0.09
External Rotators	0.09	0.32	0.20	**0.02**	0.20	0.20
Internal Rotators	0.20	1.00	0.42	**0.02**	0.09	0.09
ROM (°)						
Flexion	0.61	0.82	0.93	**0.01**	0.21	0.09
Extension	0.46	0.71	1.00	**0.01**	0.21	**0.04**
Abduction	0.47	0.42	0.87	**0.00**	0.16	**0.01**
Horiz. Adduction	0.88	0.37	0.55	0.37	1.00	0.07
External Rotation	0.52	0.67	0.87	**0.03**	0.27	0.09
Internal Rotation*	0.46	0.42	0.93	**0.00**	**0.03**	**0.02**
Postural measurement						
NSP (%)	**0.03**	0.15	0.63	**0.03**	0.12	1.00
SI (%)	0.32	0.39	0.87	0.48	0.39	0.75
LSST 1 (cm.)	0.72	0.89	0.52	0.35	0.39	0.34
LSST 2 (cm.)	0.94	0.32	0.26	0.48	0.47	0.11
LSST 3(cm.)	0.52	0.25	0.33	0.10	0.25	0.08
TKI (%)	0.75		0.75			
FHP (°)	0.87		0.23			
FSP (°)	0.52		0.78			
FIT-HaNSA						
WUT (%)	0.89	1.00	0.88	0.28	0.32	0.18
EDT (%	0.65	0.59	0.76	0.62	0.88	0.90
OHT (%)	0.10	0.16	0.10	0.33	0.38	0.62
Average	0.80	0.72	0.46	0.20	0.77	0.46
Questionnaires						
CMS	0.20	0.78	0.87	**0.00**	**0.01**	**0.04**
OSS	0.11		0.11			
DASH	0.94		0.94			
DASH_Op1	0.71		0.23			
DASH_Op2	0.25		0.74			
ULFI	0.89		0.69			
GHSF12	**0.05**		0.57			
GHSF12_PC	**0.04**		0.33			
GHSF12_MC	**0.03**		0.33			
HADS	0.05		0.47			
HADS_AC	0.09		0.87			
HADS_MC	0.06		0.94			
MPQ	0.89		0.75			

* The mean presented as the score used in CMS

By progressive comparisons, the PGs can be incorporated into a valid analytical framework. In summary, the affected shoulders in female patients with unilateral and bilateral impingement had no significant differences in between which allowed pooling them into a single group of 16 female patients with impingement. The improved subgroup had some significant differences when compared with unilaterally affected female patients, therefore, it was separated and because of its small sample size, it was decided to remove it from final comparisons. Finally, all affected shoulders in male patients were proved to be alike, therefore, gathered to form 19 male patients with impingement [Figure 4 – 2].

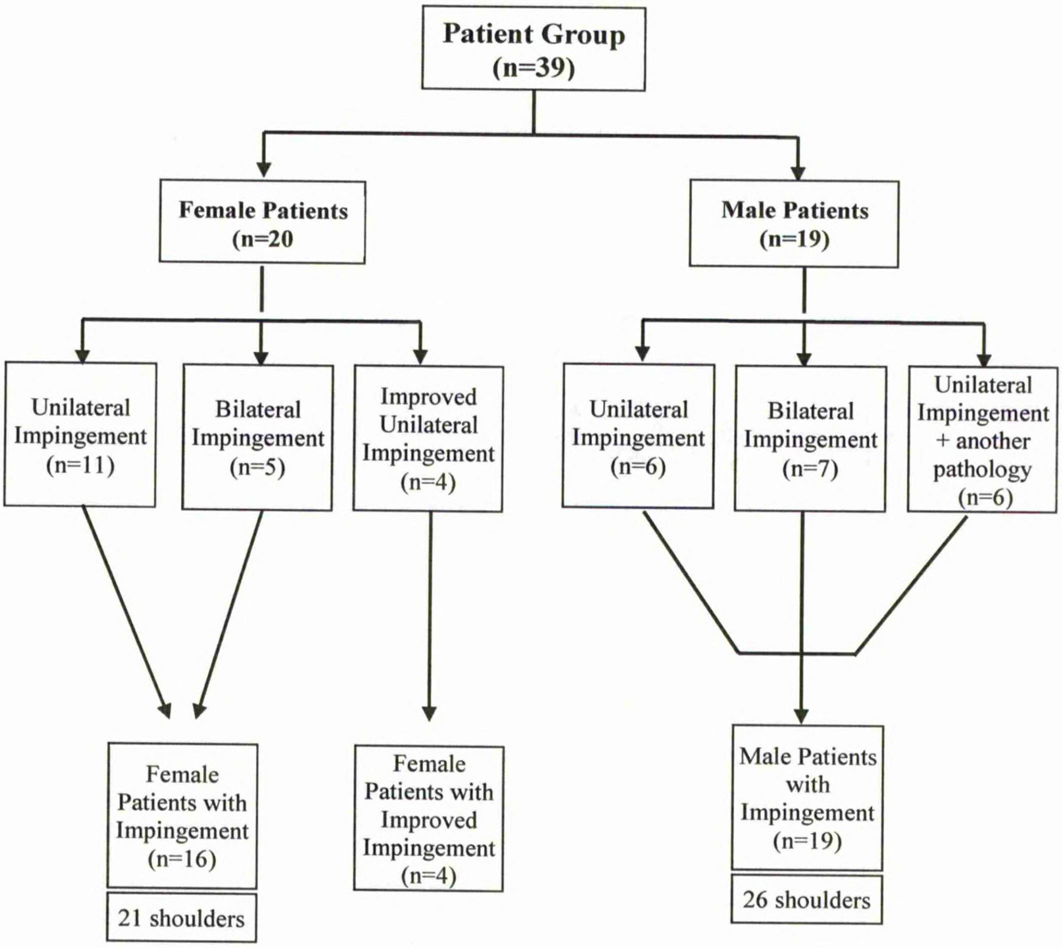


Figure 4 - 2: Pooling clinical subgroups in male and female impingement patients

5 CHAPTER FIVE: RESULTS – CLINICAL ASSESSMENT

This chapter includes the results of different clinical assessments and self-reporting questionnaires, their descriptive statistics and comparative analysis between the female patients (FP) and female controls (FC), and later between male impingement patients and controls. Results are shown as mean value and standard deviation (SD), or range, as appropriate.

Objectives:

In both impingement patients and controls:

- To assess and compare the muscle strength of four shoulder muscle groups using Mecmesin myometer.
- To assess and compare the range of motion using a goniometer and photos.
- To identify alteration of upper body posture, their association with shoulder impingement and differences from normal shoulders using simple measurements between spine and shoulder girdle anatomical landmarks.
- To assess and compare the effect of shoulder impingement on daily life shoulder activity using a functional impairment test (FIT-HaNSA)
- To document and compare subjective assessments of shoulder impingement and related health problems using seven patient-based (self-reported) questionnaires.

5.1 Female Data: Patients and Controls

Table 5 - 1: Comparisons between affected and unaffected shoulders of female patients with controls.

Comparing isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements and functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA). Bold p values are less than 0.05.

Tests	Female Impingement Affected Shoulder			*p* value	Female Controls			*p* value	Female Impingement Unaffected Shoulder		
	N	Mean	SD		N	Mean	SD		N	Mean	SD
Isometric MVC (N)											
Flexors	21	37.7	15.8	**0.00**	26	67.8	9.9	0.33	11	64.8	8.7
Abductors	21	31.4	13.2	**0.00**	26	64.1	9.1	0.29	11	59.0	10.3
External rotators	21	52.1	13.7	**0.00**	26	77.8	15.3	0.46	11	73.1	17.5
Internal rotators	21	66.0	30.6	**0.00**	26	124.4	33.4	0.34	11	109.8	41.6
ROM (°)											
Flexion	21	126.7	30.0	**0.00**	26	180.0	0.0	**0.00**	11	170.0	6.3
Extension	21	35.2	8.7	**0.00**	26	53.8	5.0	**0.00**	11	45.5	4.7
Abduction	21	111.0	31.4	**0.00**	26	180.0	0.0	**0.00**	11	165.5	13.7
Horiz. adduction	21	39.0	9.6	**0.02**	26	45.4	3.7	0.42	11	46.4	5.0
External rotation	21	53.3	16.8	**0.00**	26	86.5	4.9	**0.00**	11	68.6	11.0
Internal rotation*	21	5.6	2.5	**0.00**	26	10.0	0.0	**0.00**	11	8.7	1.8
Bilateral posture											
NSP (%)	21	161.0	8.7	1.00	26	162.0	5.5	0.97	11	161.2	8.5
SI (%)	21	70.5	6.7	0.47	26	72.1	6.7	0.32	11	69.3	7.4
LSST 1 (cm.)	21	8.8	2.0	0.61	26	9.0	0.9	0.74	11	9.5	2.2
LSST 2 (cm.)	21	9.6	1.9	0.14	26	10.3	0.9	0.79	11	10.5	1.9
LSST 3(cm.)	21	10.2	2.1	**0.01**	26	11.5	0.7	0.84	11	11.7	2.1
Axial posture											
TKI (%)	16	10.4	2.9	0.93	12	10.1	1.3				
FHP (°)	14	49.3	9.6	**0.03**	12	55.5	8.3				
FSP (°)	15	45.5	10.1	**0.02**	12	53.6	7.0				
FIT-HaNSA											
WUT (%)	16	58.4	24.1	**0.00**	18	100.0	0.0	**0.00**	6	80.3	22.9
EDT (%	16	29.8	15.8	**0.00**	18	92.1	11.8	**0.00**	6	45.6	17.6
OHT (%)	16	43.6	17.7	**0.00**	18	97.7	4.7	**0.00**	6	63.9	17.5
AVERAGE	16	43.9	17.3	**0.00**	18	96.6	4.9	**0.00**	6	63.3	17.5

* The mean presented as the score used in CMS

5.1.1 Female Isometric Maximum Voluntary Contraction

Generally, there was a pattern of gradual decrease of muscle strength when moving from the internal rotators, external rotators, flexors to abductors. The general pattern indicated that the affected shoulder in female patients demonstrated significantly less muscle strength in all muscle groups when compared with female controls and the unaffected shoulder in the same patients. Although, the muscle strength in the unaffected shoulder was comparably less than that in controls but the difference was not significant. There was about 50% reduction of muscle strength in flexors, abductors and internal rotators [Table 5 – 1].

5.1.2 Female Range of Motion

The general pattern indicated that the affected and unaffected shoulders in female patients showed a significantly reduced ROM in all shoulder movements when compared with controls. Horizontal adduction revealed less significant difference. Furthermore, the impingement patients showed that the unaffected shoulders were not as bad as the affected ones but also they were not good as healthy shoulders [Table 5 – 1].

5.1.3 Female Posture

Bilateral postural measurements showed only one significant difference between affected female shoulders and controls for LSST 3 ($p<0.05$) [Table 5 – 1].

5.1.4 Female Functional Impairment Test-Hand and Neck/Shoulder/Arm

The functional impairment test indicated a very strong significant difference when female controls were compared to affected and unaffected shoulders [Table 5 – 1].

5.1.5 Female Self-Reporting Questionnaire

Table 5 - 2: The mean scores of Constant-Murley score (CMS). A comparison between female patients and controls. Bold *p* values are less than 0.05.

CMS	Best	Worst	Female Impingement Affected Shoulder			*p* value	Female Control			*p* value	Female Impingement Unaffected shoulder		
			N	Mean	SD		N	Mean	SD		N	Mean	SD
Pain	15	0	21	7.0	3.3	**0.00**	26	15.0	0.0	**0.03**	11	14.4	1.6
Activity	20	0	21	11.1	3.5	**0.00**	26	20.0	0.0	**0.00**	11	19.1	1.5
ROM	40	0	21	23.9	7.5	**0.00**	26	39.8	0.7	**0.02**	11	38.4	2.9
Power	25	0	21	7.0	3.0	**0.00**	26	14.4	2.1	0.20	11	13.2	2.4
Total	100	0	21	49.2	14.1	**0.00**	26	88.8	1.8	**0.04**	11	85.0	6.9

The components and the total of CMS revealed that the female patients' means were significantly lower in the affected shoulders than the unaffected and healthy shoulders ($p<0.01$). The unaffected shoulders were significantly different from healthy shoulders ($p<0.05$) in all components except for power [Table 5 - 2].

The other self-reported questionnaires revealed that the mean scores – except for DASH Op12 - were significantly different between female patients and female controls [Table 5 – 3].

Table 5 - 3: The mean scores of other self-reporting questionnaires. Comparisons between female patients and controls. Bold p values are less than 0.05.

Other Questionnaires	Best	Worst	Female Impingement Affected			p value	Female Control		
			N	Mean	SD		N	Mean	SD
OSS	0	48	16	23.7	8.2	**0.00**	13	48.0	0.0
DASH	100	0	16	53.8	14.2	**0.00**	13	0.4	1.2
DASH Op1	100	0	16	22.7	26.8	**0.01**	12	0.0	0.0
DASH Op2	100	0	16	19.1	32.4	0.05	11	0.0	0.0
ULFI	100	0	16	46.8	17.3	**0.00**	13	0.0	0.0
MPQ	78	0	16	22.7	12.3	**0.00**	13	0.0	0.0
HADS	42	0	16	14.9	8.5	**0.00**	13	1.2	2.1
HADS_AC	21	0	16	8.8	4.4	**0.00**	13	0.8	1.4
HADS_DC	21	0	16	6.2	4.5	**0.00**	13	0.4	1.0
GHSF12	56	12	16	33.6	7.4	**0.00**	13	16.2	2.0
GHSF12_PC	28	6	16	16.6	3.9	**0.00**	13	8.7	1.7
GHSF12_MC	28	6	16	17.1	4.0	**0.00**	13	7.5	0.7

Female patients addressed a highly significant difference ($p<0.01$) from controls in their response of self-assessment questionnaires. DASH option 2 was the only one with $p=0.05$ and was related to recreational activity.

5.2 Male Data: Patients and Controls

Table 5 - 4: Comparisons between affected and unaffected shoulders of male patients with controls Comparing isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements and functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA). Bold *p* values are less than 0.05.

Tests	Male Impingement Affected Shoulder			*p* value	Male Controls			*p* value	Male Impingement Unaffected Shoulder		
	N	Mean	SD		N	Mean	SD		N	Mean	SD
Isometric MVC (N)											
Flexors	26	71.3	36.2	**0.00**	42	103.7	18.0	0.44	12	109.0	22.6
Abductors	26	58.9	34.6	**0.00**	42	94.5	14.6	0.96	12	95.1	19.4
External rotators	26	84.9	38.0	**0.00**	42	110.4	27.7	0.94	12	112.7	27.9
Internal rotators	26	122.6	71.1	**0.00**	42	175.8	55.4	0.29	12	194.0	52.1
ROM (°)											
Flexion	26	138.5	41.7	**0.00**	42	178.1	4.0	0.32	12	175.8	6.7
Extension	26	39.4	8.9	**0.00**	42	50.8	5.3	0.06	12	47.9	3.3
Abduction	26	129.6	45.8	**0.00**	42	178.3	4.4	0.17	12	176.7	6.5
Horiz. adduction	26	37.9	8.9	**0.02**	42	41.9	2.9	0.31	12	42.5	3.4
External rotation	26	52.9	16.4	**0.00**	42	75.2	9.2	**0.03**	12	67.1	10.3
Internal rotation*	26	5.3	2.4	**0.00**	42	9.7	0.8	**0.00**	12	8.8	1.0
Bilateral posture											
NSP (%)	26	157.0	9.9	0.13	42	161.5	13.4	**0.00**	12	149.7	6.8
SI (%)	26	75.6	8.3	0.34	42	73.5	6.1	0.22	12	74.4	6.0
LSST 1 (cm.)	26	9.7	1.5	0.75	42	9.6	1.2	0.87	12	9.7	1.8
LSST 2 (cm.)	26	10.9	2.0	0.40	42	10.4	1.3	0.22	12	11.0	1.8
LSST 3(cm.)	26	11.6	1.2	0.35	42	11.9	1.0	0.54	12	12.0	1.6
Axial posture											
TKI (%)	21	11.8	2.1	0.14	18	10.5	2.4				
FHP (°)	19	52.5	5.9	0.10	18	47.0	11.4				
FSP (°)	19	61.9	9.4	**0.00**	18	49.7	9.2				
FIT-HANSA											
WUT (%)	18	69.8	32.1	**0.00**	22	100.0	0.0	0.06	6	96.5	8.6
EDT (%	17	51.9	29.2	**0.00**	22	96.8	7.1	0.05	6	71.7	33.7
OHT (%)	17	60.0	25.8	**0.00**	22	99.2	2.7	**0.00**	6	73.2	14.1
AVERAGE	18	59.9	26.0	**0.00**	22	98.5	3.2	**0.01**	6	84.4	19.8

* The mean presented as the score used in CMS

5.2.1 Male Isometric Maximum Voluntary Contraction

Generally, there was a pattern of gradual decrease of muscle strength when moving from the internal rotators, external rotators, flexors to abductors. The general pattern indicated that the affected shoulders in male patients exhibited lower muscle strength in all muscle groups when compared with the shoulders of male controls and the unaffected shoulders in the same patients. Although, the muscle strength in the unaffected shoulder was comparably less than that in controls but the difference was not significant [Table 5 – 4].

In both sexes, the pattern of changes in muscle strength was similar, and the significant difference was higher (p<0.01) between flexors, abductors, external and internal rotators of patients and controls. The significant difference was lower ($p\leq$ 0.05) when the internal rotators of female patients and external rotators of male patients were compared between the affected and unaffected shoulders.

5.2.2 Male Range of Motion

The affected shoulders in male patients showed a significantly reduced ROM in all shoulder movements when compared with the shoulders of male controls as well as the unaffected shoulders of male patients. Horizontal abduction revealed less significant difference (p>0.01). The ROM of the unaffected shoulders was not significantly different from those of controls except for external and internal rotation [Table 5 – 4].

Both male and female groups showed similar pattern of changes and statistical significance in ROM. Generally, the unaffected shoulders of male patients were more similar to male controls; whereas in female patients a statistical significant difference was observed between the unaffected shoulders and female controls.

5.2.3 Male Postural Measurements

Generally, the differences in the bilateral postural measurements between the compared male groups were quantitatively small and statistically not significant. The only significant difference was detected for NSP when the unaffected shoulders were compared with either the affected shoulders or the controls. Furthermore, the FSP was highly significantly different between the compared groups [Table 5 – 4].

In both female and male patients, when compared to controls of the same gender, there were no major differences in postural measurements except in LSSTP3, FHP and FSP in females; and FSP in males. The axial postural measurements were generally higher in male controls than male patients with a significant difference in FSP between the two groups.

5.2.4 Male Functional Impairment Test-Hand and Neck/Shoulder/Arm

The mean duration (%) of each task and the average of their performance was highly significantly reduced in the affected shoulders of male patients when compared to controls ($p<0.01$). The tasks were performed only on 6 unaffected shoulders and were significantly different from controls for the OHT [Table 5 – 4].

5.2.5 Male Self-Reporting Questionnaires

Table 5 - 5: The mean scores of Constant-Murley score (CMS). A comparison between male patients and controls. Bold p values are less than 0.05.

CMS	Best	Worst	Male Impingement Affected Shoulder			p value	Male Control			p value	Male Impingement Unaffected shoulder		
			N	Mean	SD		N	Mean	SD		N	Mean	SD
Pain	15	0	25	6.6	4.2	**0.00**	42	14.4	1.6	0.06	12	14.2	1.3
Activity	20	0	26	10.3	5.5	**0.00**	42	19.6	1.2	**0.00**	12	19.1	1.5
ROM	40	0	26	23.5	10.5	**0.00**	42	39.5	2.0	**0.03**	12	38.5	3.0
Power	25	0	26	14.2	7.6	**0.00**	42	21.1	2.8	0.76	12	21.0	3.4
Total	100	0	26	54.0	23.9	**0.00**	42	94.8	4.3	0.32	12	93.0	6.9

Generally, the affected shoulder of male patients showed a significantly lower score than the controls. Every component of CMS revealed that the means were significantly lower in the affected shoulders than the controls. The unaffected shoulders showed a significant difference only for activity and ROM ($p<0.01$ and <0.05 respectively) [Table 5 – 5].

Table 5 - 6: The mean scores of other self-reporting questionnaires. Comparisons between male patients and controls. Bold *p* values are less than 0.05.

Other Questionnaires	Best	Worst	Male Impingement Patients			*p* value	Male Control		
			N	Mean	SD		N	Mean	SD
OSS	0	48	18	24.2	8.1	**0.00**	21	46.4	2.6
DASH	100	0	18	50.5	17.4	**0.00**	21	1.9	3.5
DASH Op1	100	0	18	39.6	32.3	**0.00**	21	0.6	1.9
DASH Op2	100	0	18	34.0	36.2	**0.00**	21	1.2	5.5
ULFI	100	0	18	51.1	17.5	**0.00**	21	2.9	7.1
MPQ	78	0	18	28.0	18.7	**0.00**	21	1.7	3.9
HADS	42	0	18	16.2	10.8	**0.00**	21	0.3	0.7
HADS_AC	21	0	18	9.2	5.8	**0.00**	21	0.3	0.7
HADS_DC	21	0	18	6.3	6.0	**0.00**	21	0.0	0.0
GHSF12	56	12	18	33.3	10.2	**0.00**	21	17.4	3.4
GHSF12_PC	28	6	18	16.5	4.6	**0.00**	21	9.0	2.1
GHSF12_MC	28	6	18	18.1	4.9	**0.00**	21	8.4	1.7

Each self-reporting questionnaire revealed that the mean score was significantly different between male patients and male controls

5.3 Combined Pain Score

The primary reason for patients to seek referral from their GP to the specialist shoulder teams is pain. Patients with SIS have particular patterns of pain - worst during particular movements and in specific places.

A combined pain score (CPS) was formulated from the items related to pain in the following self-reporting questionnaires: (1) CMS (item 1); (2) OSS (items 1, 8 and12) (3) DASH (Items 24 and 25); and (4) GHSF-12 (item 6). Both graphs in Figure 4 – 1 and Figure 4 – 2 reflected the percentage of pain intensity in female and male study groups with the lowest score (0%) indicating 'the most severe pain' and the highest score (100%) indicating 'no pain at all' in the clinical subgroups of female and male patients.

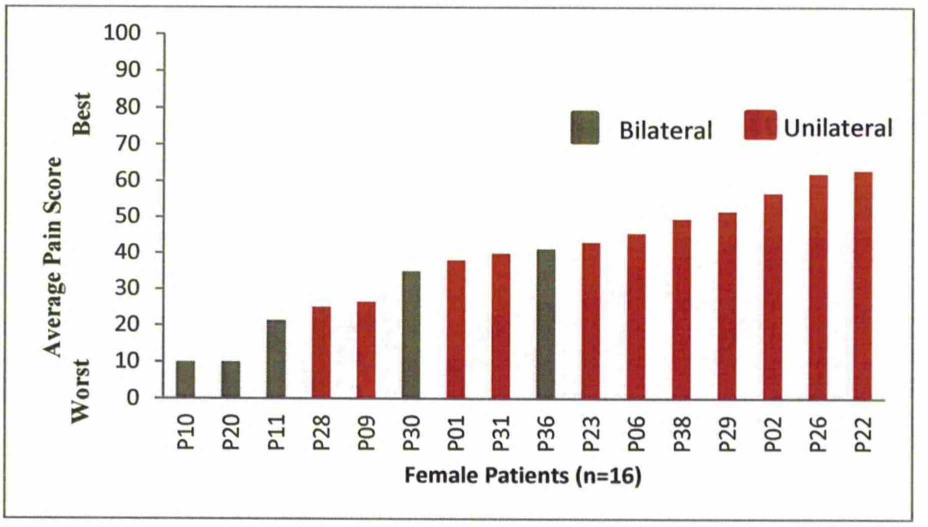


Figure 5 - 1: Combined Pain Score (CPS) in individual female patients.

Severity of pain arranged from worst to best in female patients with unilateral and bilateral involvement.

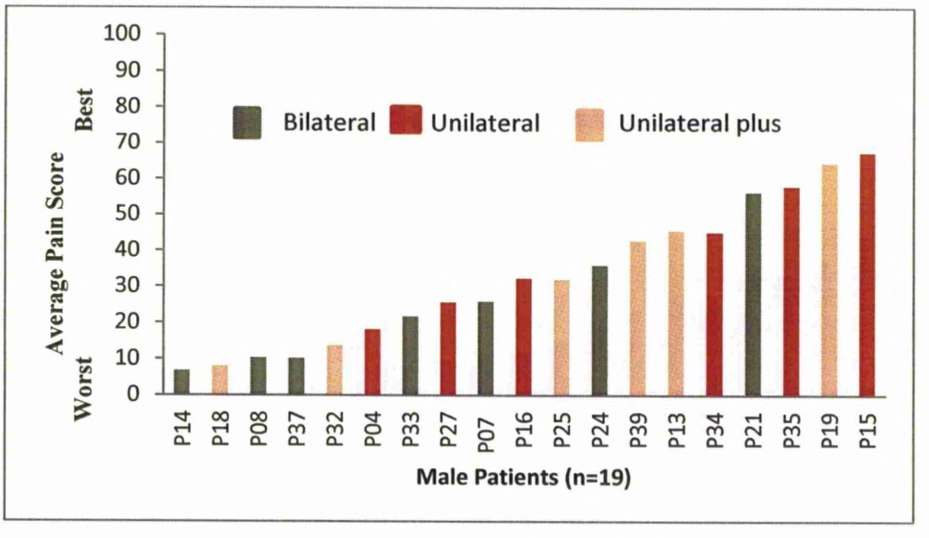


Figure 5 - 2: Combined Pain Score (CPS) in individual male patients.

Severity of pain arranged from worst to best in male patients with unilateral, bilateral and complicated unilateral impingement.

Both female and male patients had the worst pain intensity at about 10% and the least experienced pain about 65% score. A higher percentage of patients with bilateral impingement had severe pain in the range of 10% – 20%, while in the majority of unilateral impingement it was distributed in the range of 20% - 65%.

The shoulder pain was localized anterolateral to the acromion process in all female patients. In addition to anterolateral pain 6/10 shoulders in patients with bilateral involvement had associated pain at the top of the shoulder around acromioclavicular joint and referred arm pain in 5/10 with bilateral affection.

Regarding male patients, all non-complicated unilateral shoulders (8/8), 6/14 with bilateral involvement and 2/6 with complicated unilateral impingement had only anterolateral pain to the acromion. The remaining bilaterally involved shoulders had an associated pain to the top of shoulder and extension to lateral aspect of the arm, while the rest of complicated unilateral shoulders had associated pain with extension to the back. Those with pain score less than 20% showed considerable restriction of shoulder movements.

5.4 Overall Non-Electromyography Data Correlations

Table 5 - 7: Inter-correlation between combined pain score (CPS), isometric maximum voluntary contraction (MVC), range of motion (ROM), postural measurements, functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA) and Constant-Murley score. The indicated p values are less than 0.05 (statistical significance).

	CPS	FLEXORS	ABDUCTORS	Ext Rot	Int Rot	Flexion	Abduction	ExtRotation	IntRotation	NSPI	SI	LSSTP1	LSSTP2	LSSTP3	Thorkypind	FHP	FSP	WUT	EDT	OHT	AVERAGE	PAIN	ACTIVITY	ROM	POWER
CPS																									
FLEXORS	.026																								
ABDUCTORS		.000																							
Ext Rot		.000	.000																						
Int Rot	.039	.000	.000	.000																					
Flexion	.022	.001	.000	.002	.000																				
Abduction	.040	.001	.000	.001	.000	.000																			
ExtRotation	.007	.023	.013			.000	.000																		
IntRotation	.013	.044	.010	.041	.003	.000	.000	.000																	
NSPI				.041	.015																				
SI		.011	.001		.001					.025															
LSSTP1																									
LSSTP2												.000													
LSSTP3												.000	.000												
Thorkypind								.006	.045																
FHP								.028					.034												
FSP						.032	.022								.023										
WUT	.037	.001	.000	.006	.002	.057	.025																		
EDT	.021	.020	.004	.021	.044	.090												.000							
OHT		.001	.000	.004	.004													.000	.001						
AVERAGE	.007	.000	.000	.005	.002	.028	.014											.000	.000	.000					
PAIN	.000	.026			.025	.046			.028									.040			.026				
ACTIVITY	.000	.003	.028	.013	.009	.006	.016	.020	.004											.017	.016	.000			
ROM	.011		.017		.010	.000	.000	.001	.000			.028										.002	.000		
POWER		.000	.000	.000	.000	.002	.000				.006							.000	.000	.000	.000				
TOTAL	.000	.000	.000	.000	.000	.000	.000	.000	.000									.012		.008	.003	.000	.000	.000	.000

Positive correlation

Negative correlations

Table 5 – 7 showed an overall (all female and male patients) Pearson Coefficient Correlation of the CPS, isometric MVC, ROM, FIT-HaNSA and CMS. The CPS had positive significant correlation with isometric MVC (flexors and internal rotators), ROM (flexion, abduction, internal and external rotation), FIT-HaNSA (WUT and EDT) and CMS (all components except power). No correlation was detected between CPS and postural measurements. Additionally, isometric MVC was significantly positively correlated with ROM (except external rotation), FIT-HaNSA, posture (only SI) and CMS; while negatively correlated to NSP, the first component of posture. Overall, a strong relationship was evident between pain, muscle strength (isometric MVC), ROM and functional impairment in patients with SIS.

6 CHAPTER SIX: ELECTROMYOGRAPHY RESULTS – MUSCLE ACTIVATION

EMG was recorded from 15 shoulder muscles on one side during 3 functional tasks simulating daily living activities (chapter 3- Material and Methods, section 3.6.8.1). With a 1 kg load in hand, the tasks were progressed gradually from an internal and external rotation task (IERT) with the arm at the side of the body to forward reaching (arm elevation and lowering tasks) between the waist and eye levels and known as waist-up task (WUT) and eye-down task (EDT). The average of 10 full cycles of each task for study groups and controls was considered to achieve the following objectives:

(1) To determine differences in the time spent during the shelf contact and movement between shelves at each phase of the three functional tasks.

(2) To compare patterns of shoulder muscle activation during functional tasks using quantitative and qualitative techniques.

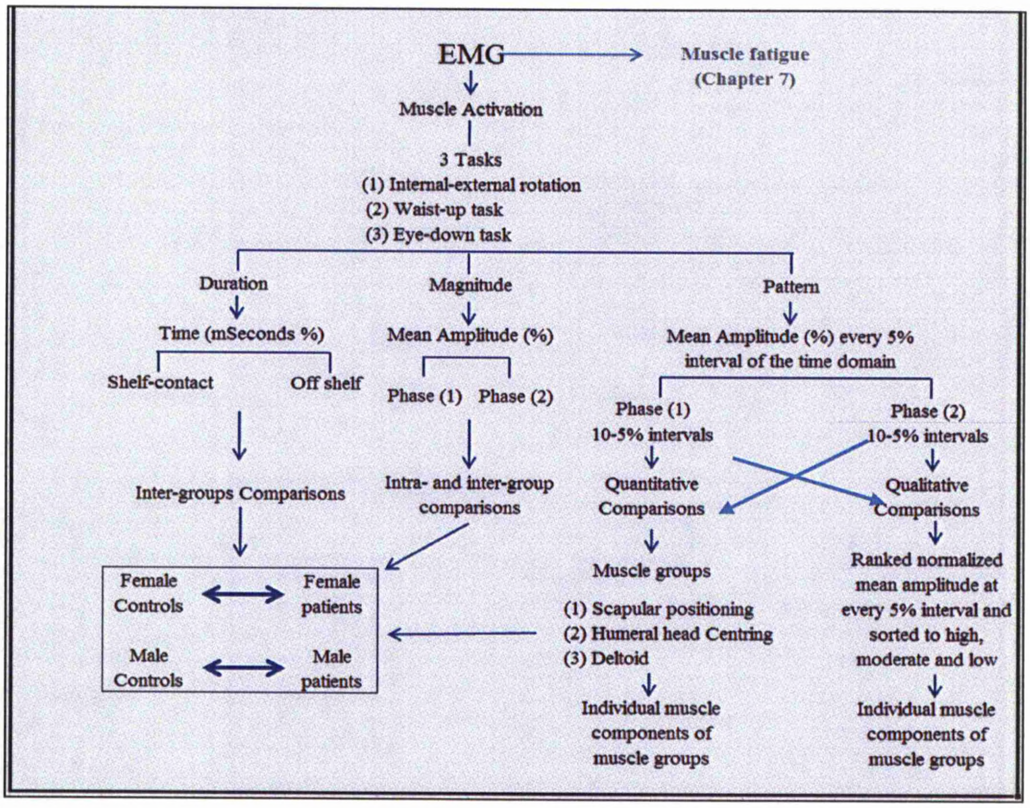
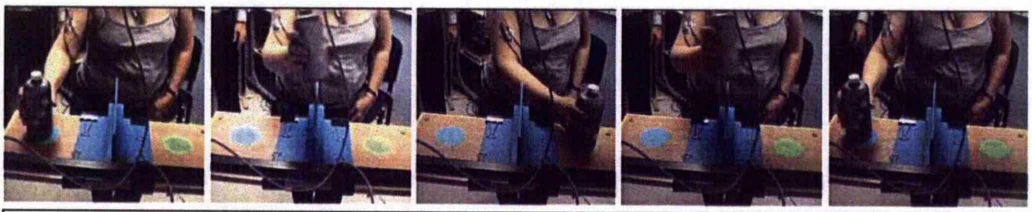


Figure 6 - 1: Flowchart results of muscle activation during three different tasks: Internal-external rotation, waist-up and eye-down tasks.

6.1 Internal and External Rotation Task

The Internal and External Rotation Task (IERT) involved dynamic/cyclic movements of shoulder internal (phase 1) and external (phase 2) rotation following an adjusted metronome to achieve one full cycle within 2 seconds (i.e. one second for each phase). With the arm close to the side of the body, each participant lifted a 1-kg weight over a barrier placed horizontally on a shelf at the waist level for 10 successive cycles. The applied position and movements during this task did not require arm elevation and as a result provided a convenient pain-free assessment of the shoulder performance in SIS patients.



Phase (1) Internal Rotation	Phase (2) External Rotation

Figure 6 - 2: Internal (phase 1) and external (phase 2) rotation task (IERT)

Moving a load of 1 kg across a shelf parallel to horizontal plane and placed at the waist level. The weight was lifted over a bridge (blue colour) placed in a perpendicular plane on the shelf.

6.1.1 Cycle Duration

The average duration of 10 cycles was divided into the duration of shelf-contact and off-shelf time during internal rotation (phase1) and external rotation (phase2) of the task. The percentage of shelf-contact and off-shelf in each phase was calculated from the averaged cycle duration and presented in Table 6- 1. Taking into account the female groups, the mean duration of shelf-contact was significantly higher while the off-shelf was significantly lower in SIS patients compared to the controls for both phase (1) and (2) of the IERT. Concerning the male groups, though there was no significant difference of the compared on-shelf and off-shelf mean durations at both phases but they showed reversed trend to that reported in female groups.

Table 6 - 1: Comparing the time % of the phase components (shelf-contact and off-shelf) during internal-external rotation task (IERT).

The comparisons were within female (subacromial impingement syndrome (SIS) patients, n=13; controls, n=13) and male (SIS patients, n=16; controls, n=20) subjects. Bold p values <0.01.

Group	IERT	Phase (1) Internal Rotation					Phase (2) External Rotation				
		SIS Patients		Controls		p value	SIS Patients		Controls		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female	Shelf-Contact	9.3	3.4	5.2	2.2	**0.00**	8.7	3.5	4.7	1.6	**0.00**
	Off-Shelf	40.9	3.4	45.1	2.1	**0.00**	41.2	3.7	45.1	2.2	**0.00**
Male	Shelf-Contact	11.2	5.3	9.3	5.6	0.45	10.0	5.1	8.8	5.0	0.45
	Off-Shelf	39.5	5.5	41.3	5.3	0.41	39.3	5.1	40.7	5.3	0.65

6.1.2 Mean Amplitude

As previously described in 'Chapter 3 – Material and Methods, section 3.6.11.4', the raw EMG data of muscle activation during phase 1 and phase 2 of the IERT was normalized to the mean amplitude of each phase (Amplitude %) to make it comparable between the study groups. Table 6 - 2 and Table 6 – 3 included intra-group and inter-group comparisons, respectively, of normalized mean amplitude in each phase of IERT.

Regarding intra-group comparisons of phase 1 and phase 2 mean amplitude %, matched significant differences in female patients and female controls were evident for SA, LD,TM, ISP, AD and MD. In addition, UT and LT in female patients and SUBS in female control subjects revealed isolated significant differences [Table 6 - 2]. In male groups, the matched significant differences were evident in UT, TM, ISP, and PD. LS, LT, PM and AD were significantly different in male patients; while SSP and MD showed significant difference in male controls [Table 6 - 2]. The comparison of phase mean amplitude % between patients and controls of both sexes revealed very limited significant differences. The comparison between female patients and controls showed significant difference for SUBS in both phases and AD in phase 1; while between male groups, the only significant difference was noted for LS in phase 1 [Table 6 - 3].

Table 6 - 2: Normalized mean amplitude (%) comparison between phase 1 and phase 2 in female (subacromial impingement syndrome (SIS) patients=16, controls=13) and male (SIS patients = 19, controls =20) subjects during internal-external rotation task.

Muscle Groups	Muscle	SIS Patients					Controls				
		Phase 1		Phase 2		*p* value	Phase 1		Phase 2		*p* value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular positioning	LS	98.0	7.0	100.6	6.6	0.44	101.2	5.9	98.5	6.8	0.51
	UT	92.8	6.5	104.8	8.4	0.00	94.7	10.8	104.0	10.1	0.17
	LT	91.4	8.3	106.4	8.8	0.00	97.1	7.8	102.9	7.6	0.17
	SA	103.5	3.9	95.6	3.9	0.00	106.4	7.7	93.6	7.4	0.01
	RM	93.7	12.4	105.2	12.1	0.15	97.4	11.3	102.7	11.2	0.75
Humeral Head Centring	LD	103.0	3.7	96.4	3.7	0.01	104.3	4.6	95.8	4.4	0.01
	TM	91.1	6.3	109.0	7.0	0.00	94.3	5.7	106.1	6.1	0.01
	PM	109.5	9.0	90.2	9.0	0.00	115.1	8.7	84.6	9.1	0.00
	BB	100.3	4.0	99.4	4.6	0.72	100.7	4.3	99.6	4.9	0.75
	SSP	95.3	12.4	103.8	13.1	0.35	98.8	8.5	101.3	8.7	0.86
	ISP	91.2	9.3	108.9	10.0	0.01	95.3	6.7	105.2	7.5	0.02
	SUBS	100.2	7.5	101.5	8.8	0.68	107.3	8.0	92.6	8.9	0.01
Deltoid	AD	106.9	6.0	92.8	5.9	0.00	112.4	6.8	87.7	6.9	0.00
	MD	98.1	8.7	101.5	8.4	0.30	101.9	8.1	98.6	7.9	0.75
	PD	93.7	7.5	105.8	7.6	0.00	93.5	10.5	106.9	10.2	0.00
Male Group											
Scapular positioning	LS	96.2	3.4	103.2	3.8	0.00	99.0	4.8	101.7	5.5	0.30
	UT	89.8	12.5	109.6	12.2	0.00	94.7	8.8	106.2	8.0	0.01
	LT	95.0	8.4	105.1	8.4	0.01	96.1	9.1	104.9	10.0	0.05
	SA	100.7	6.4	98.2	6.0	0.29	100.2	9.4	100.6	9.3	0.63
	RM	95.2	12.8	102.0	10.4	0.20	95.6	7.8	103.7	8.6	0.06
Humeral Head Centring	LD	101.3	5.4	98.2	5.6	0.18	102.1	4.8	98.5	5.2	0.10
	TM	88.4	6.4	111.9	6.3	0.00	90.2	9.8	110.7	10.4	0.00
	PM	106.9	11.9	93.4	10.8	0.01	106.8	13.4	94.4	14.1	0.06
	BB	101.0	9.7	99.3	9.0	0.56	101.4	6.4	99.3	7.3	0.33
	SSP	94.4	15.1	101.4	15.5	0.10	95.6	8.5	105.0	8.1	0.02
	ISP	87.6	9.0	113.1	9.4	0.00	90.5	8.8	110.6	10.2	0.00
	SUBS	96.8	11.2	100.2	8.7	0.27	99.3	6.8	101.5	6.9	0.65
Deltoid	AD	104.3	7.9	95.3	7.7	0.03	102.7	10.5	98.2	10.4	0.21
	MD	97.4	8.1	102.3	6.9	0.05	95.6	5.8	105.2	5.1	0.00
	PD	90.1	7.4	109.8	7.1	0.00	93.1	7.1	107.9	7.8	0.00

Table 6 - 3: Normalized mean amplitude (%) comparisons in female (subacromial impingement syndrome (SIS) patients=16, controls=13) and male (SIS patients = 18, controls =19) subjects during phases 1 and 2 of the internal-external rotation task.

Muscle Groups	Muscle	Phase 1					Phase 2				
		SIS Patients		Control		*p* value	SIS Patients		Control		*p* value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular positioning	LS	98.0	7.0	101.2	5.9	0.24	100.6	6.6	98.5	6.8	0.36
	UT	92.8	6.5	94.7	10.8	0.54	104.8	8.4	104.0	10.1	0.57
	LT	91.4	8.3	97.1	7.8	0.08	106.4	8.8	102.9	7.6	0.25
	SA	103.5	3.9	106.4	7.7	0.29	95.6	3.9	93.6	7.4	0.46
	RM	93.7	12.4	97.4	11.3	0.38	105.2	12.1	102.7	11.2	0.55
Humeral Head Centring	LD	103.0	3.7	104.3	4.6	0.20	96.4	3.7	95.8	4.4	0.48
	TM	91.1	6.3	94.3	5.7	0.20	109.0	7.0	106.1	6.1	0.20
	PM	109.5	9.0	115.1	8.7	0.16	90.2	9.0	84.6	9.1	0.17
	BB	100.3	4.0	100.7	4.3	0.83	99.4	4.6	99.6	4.9	0.79
	SSP	95.3	12.4	98.8	8.5	0.36	103.8	13.1	101.3	8.7	0.60
	ISP	91.2	9.3	95.3	6.7	0.16	108.9	10.0	105.2	7.5	0.19
	SUBS	100.2	7.5	107.3	8.0	**0.04**	101.5	8.8	92.6	8.9	**0.02**
Deltoid	AD	106.9	6.0	112.4	6.8	**0.03**	92.8	5.9	87.7	6.9	0.05
	MD	98.1	8.7	101.9	8.1	0.20	101.5	8.4	98.6	7.9	0.38
	PD	93.7	7.5	93.5	10.5	0.46	105.8	7.6	106.9	10.2	0.79
Male Group											
Scapular positioning	LS	96.2	3.4	99.0	4.8	**0.04**	103.2	3.8	101.7	5.5	0.25
	UT	89.8	12.5	94.7	8.8	0.43	109.6	12.2	106.2	8.0	0.58
	LT	95.0	8.4	96.1	9.1	0.54	105.1	8.4	104.9	10.0	0.81
	SA	100.7	6.4	100.2	9.4	0.38	98.2	6.0	100.6	9.3	0.10
	RM	95.2	12.8	95.6	7.8	1.00	102.0	10.4	103.7	8.6	0.66
Humeral Head Centring	LD	101.3	5.4	102.1	4.8	0.61	98.2	5.6	98.5	5.2	0.90
	TM	88.4	6.4	90.2	9.8	0.72	111.9	6.3	110.7	10.4	1.00
	PM	106.9	11.9	106.8	13.4	0.74	93.4	10.8	94.4	14.1	1.00
	BB	101.0	9.7	101.4	6.4	0.81	99.3	9.0	99.3	7.3	0.88
	SSP	94.4	15.1	95.6	8.5	0.95	101.4	15.5	105.0	8.1	0.45
	ISP	87.6	9.0	90.5	8.8	0.33	113.1	9.4	110.6	10.2	0.53
	SUBS	96.8	11.2	99.3	6.8	0.38	100.2	8.7	101.5	6.9	0.97
Deltoid	AD	104.3	7.9	102.7	10.5	0.63	95.3	7.7	98.2	10.4	0.35
	MD	97.4	8.1	95.6	5.8	0.32	102.3	6.9	105.2	5.1	0.11
	PD	90.1	7.4	93.1	7.1	0.26	109.8	7.1	107.9	7.8	0.74

6.1.3 Muscle Activation Pattern during Internal-External Rotation Task

EMG recordings during repeated dynamic standardised movements were familiar to the participants in the study that allowed the identification of different patterns of muscle activation. The normalization of the EMG raw signals to the mean amplitude was undertaken to facilitate comparisons between patients and controls (Chapter 3 - Material and Methods: section 3.6.11.4.1).

6.1.3.1 Muscle Activation Pattern for muscle groups during Internal-External Rotation Task

6.1.3.1.1 Patterns of Muscle Groups in Female Participants

In female controls [Figure 6 - 21], the SP muscle group was the initial leading muscle group at the level of external shelf contact (early phase 1) followed by the HHC and deltoid groups. As the arm initially attempted internal rotation, there was a steady decline in the contribution of the 3 groups with HHC group in advance (the arm was rotated internally towards neutral position). As the hand passed over the perpendicular bridge and advanced towards the extreme position of internal rotation and away from neutral position, the contribution of all muscles increased with simultaneous steep curves. In the second half of internal rotation, the deltoid group was the initial leading muscle followed by the HHC group while the SP group showed less contribution. Additionally, it was obvious that the SP group was the initial leading muscle during the shelf-contact of phase 2. As the external rotation was initiated and the arm rotated towards neutral position, we could see similar pattern to the activity in phase 1 except that the SP and HHC groups were leading the activity , while the deltoid was more declined. In the second half of external rotation, the pattern was again similar to that in phase 1 except that the SP muscle group increased its contribution to occupy the second position after the deltoid.

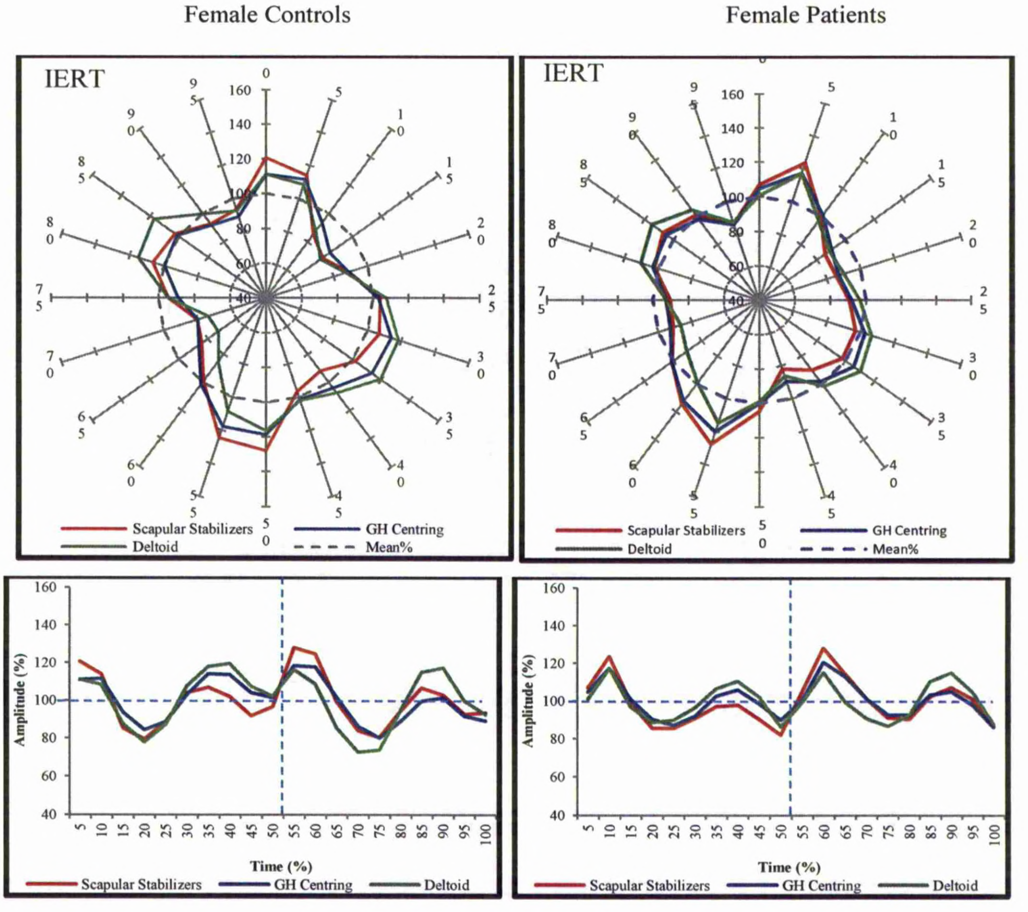
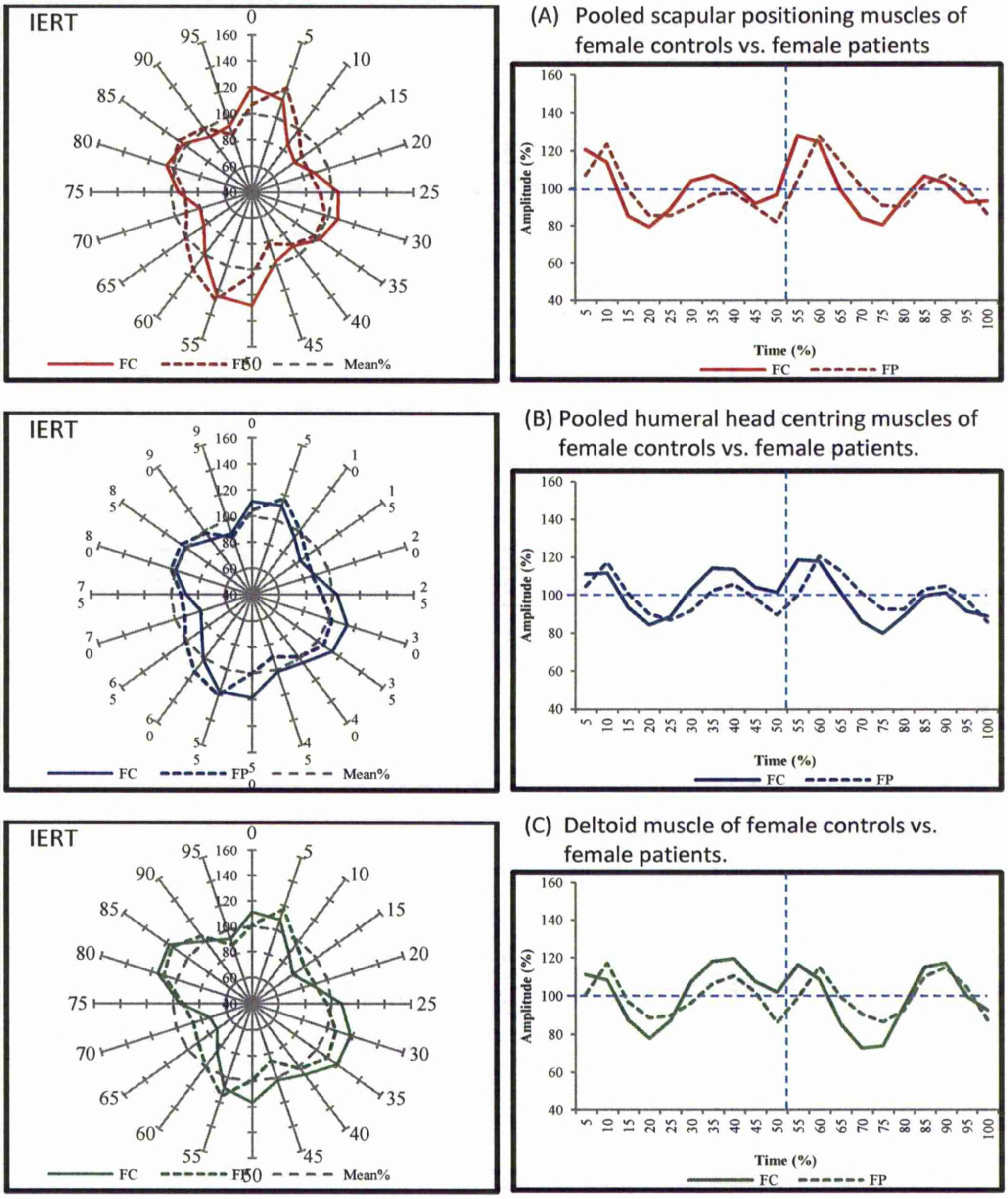


Figure 6 - 3: Activation patterns of shoulder muscle groups during internal-external rotation task (IERT).

Scapular positioning muscles (LS, UT, LT, SA and RM), humeral head centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) in female controls (left) and female impingement patients (right)

Regarding female patients [Figure 6 - 3 and Figure 6 - 4], although the general pattern appeared similar to that in female controls, there were some alterations in the 3 muscle groups of patients as the following: (1) a sharp rise in response to the initiation of either internal or external movements though no significant difference was detected, (2) lower contribution of activity which was evident and significantly different at mid-phase 1 for SP and HHC groups (p<0.05 at 30% interval for both and at 35% for HHC group), end of phase 1 for all muscle groups (p<0.05, at 50% interval), early phase 2 for all muscle groups (p<0.05, at 55% interval), and finally about mid-phase 2 for all muscle groups (p<0.05, at 70% and 75% intervals), (3) significant higher activity level at the first half of external rotation (p<0.05, at 70%

and 75%), and (4) obvious delay in patients' activity demonstrated by the shift of the curves to the right.



%	5	10	15	20	25	**30**	35	40	45	**50**	**55**	60	65	**70**	**75**	80	85	90	95	100
(A)	0.2	0.25	0.1	0.54	0.51	**0.02**	0.15	0.43	0.73	**0.03**	**0.03**	0.48	0.13	**0.01**	**0.05**	0.46	0.43	0.46	0.1	0.31
(B)	0.2	0.16	0.13	0.51	0.54	**0.01**	**0.01**	0.16	0.14	**0.01**	**0.01**	0.51	0.07	**0.01**	**0.01**	0.2	0.38	0.38	0.07	0.43
(C)	0.2	0.34	0.14	0.14	0.63	0.16	0.16	0.31	0.26	**0.01**	**0.03**	0.43	0.07	**0.02**	**0.05**	0.93	0.46	0.66	0.57	0.43

Figure 6 - 4: Comparing muscle groups between female controls (FC) and patients (FP) during internal-external rotation task (IERT).

The statistical difference (*p* value) at every 5% interval of (A) Scapular Positioning muscles, (B) Humeral head centring muscles, and (C) Deltoid. Bold values are statistically significant (p<0.05).

6.1.4 Patterns of Muscle Groups in Male Participants

Male Controls Male Patients

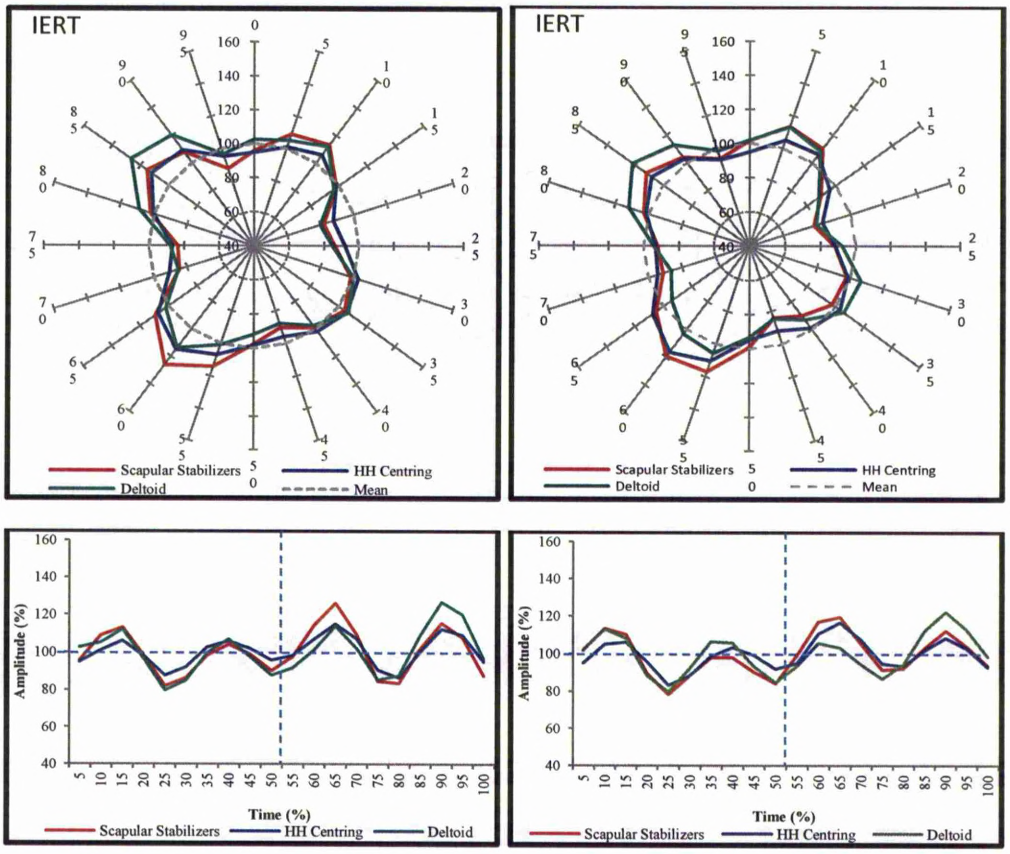
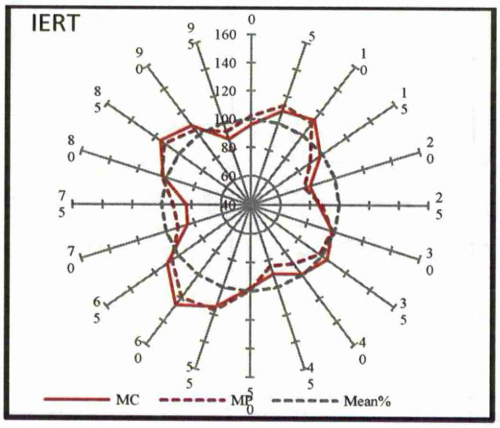


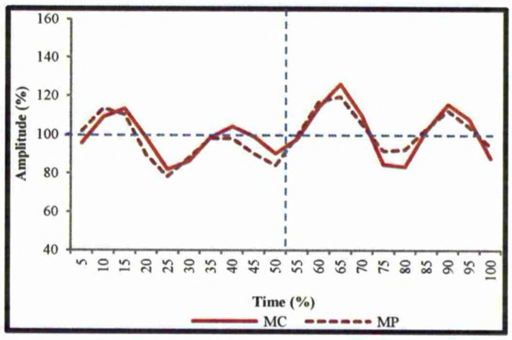
Figure 6 - 5: Activation patterns of shoulder muscle groups during internal-external rotation task (IERT).

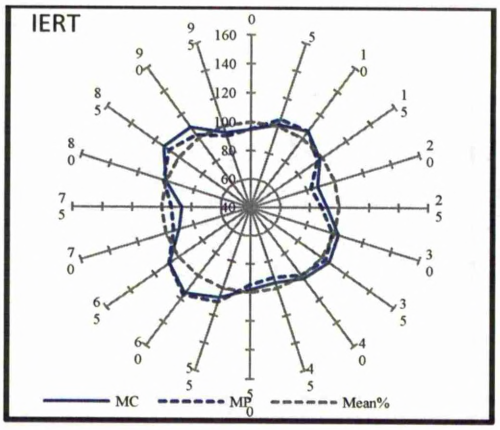
Scapular positioning muscles (LS, UT, LT, SA and RM), humeral head centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) in male controls (left) and male impingement patients (right)

In male controls [Figure 6 - 5], though the deltoid started at a highest level briefly, the SP muscle group crossed upwards and lead the activity that was followed by deltoid and then HHC group at the level of external shelf contact (early phase 1). As the arm initially attempted internal rotation there was a steady decline of the SP and deltoid more than the HHC group (the arm was rotated internally towards neutral position). As the hand passed over the perpendicular bridge away from neutral position, the contribution of all muscle groups increased with simultaneous steep curves that were led by the HHC group. In the second half of internal rotation, they showed further lazy rise in activity, although HHC group was still leading and SP group showed inter-changeable level of activity with the deltoid. In addition, it was clear that the SP group was leading the activity during the shelf-contact of phase 2, followed by HHC and lastly the deltoid muscles. As the external rotation was initiated, a similar pattern was evident as in phase 1. In the second half of external rotation, the 3 groups showed acute elevation with higher contribution by the deltoid while the other two were equivocal in contribution. Finally, they showed a gradual decline to the end. Although no significant difference was evident on comparing the individual groups between male controls and patients, it was obvious that the patients' averaged curves were shifted to the left (events took place earlier than in the controls) [Figure 6 - 5 and Figure 6 - 6].

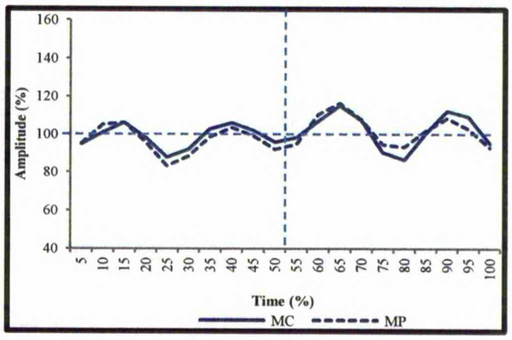


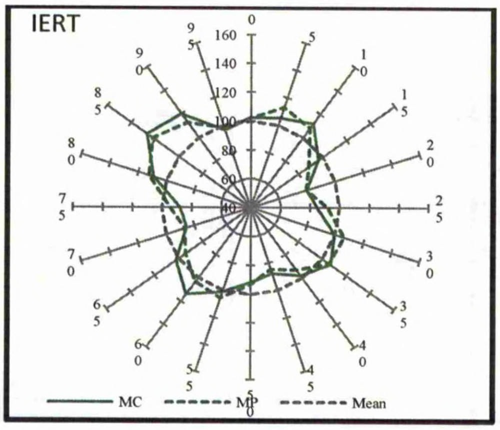
(A) Pooled scapular positioning muscles of male controls vs. male patients.



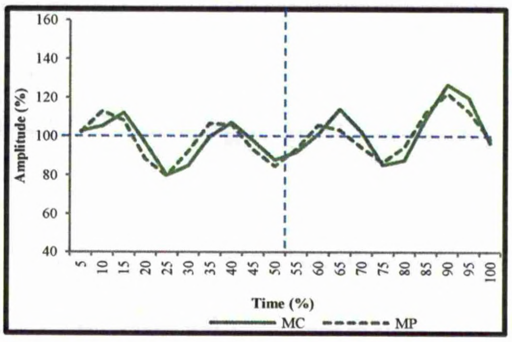


(B) Pooled humeral head centring muscles of male controls vs. male patients.





(C) Deltoid muscle of male controls vs. male patients.



%	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(A)	0.73	0.91	0.85	0.33	0.41	0.61	0.95	0.10	**0.05**	0.49	0.98	0.98	0.66	0.90	0.09	0.06	0.98	0.43	0.17	0.35
(B)	0.95	0.73	0.95	0.64	0.26	0.59	0.39	0.57	0.34	0.55	0.45	0.49	0.85	1.00	0.41	0.07	0.92	0.47	0.11	0.89
(C)	1.00	0.47	0.75	0.89	0.90	0.22	0.20	0.94	0.34	0.84	0.95	0.51	0.25	0.39	0.85	0.17	0.83	0.39	0.24	0.98

Figure 6 - 6: Comparing muscle groups between male controls (MC) and patients (MP) during internal-external rotation task (IERT).

The statistical difference (*p* value) at every 5% interval of (A) Scapular Positioning muscles, (B) Humeral head centring muscles, and (C) Deltoid. Bold values are statistically significant (p<0.05).

6.1.5 Patterns of Individual Muscles in Female Participants

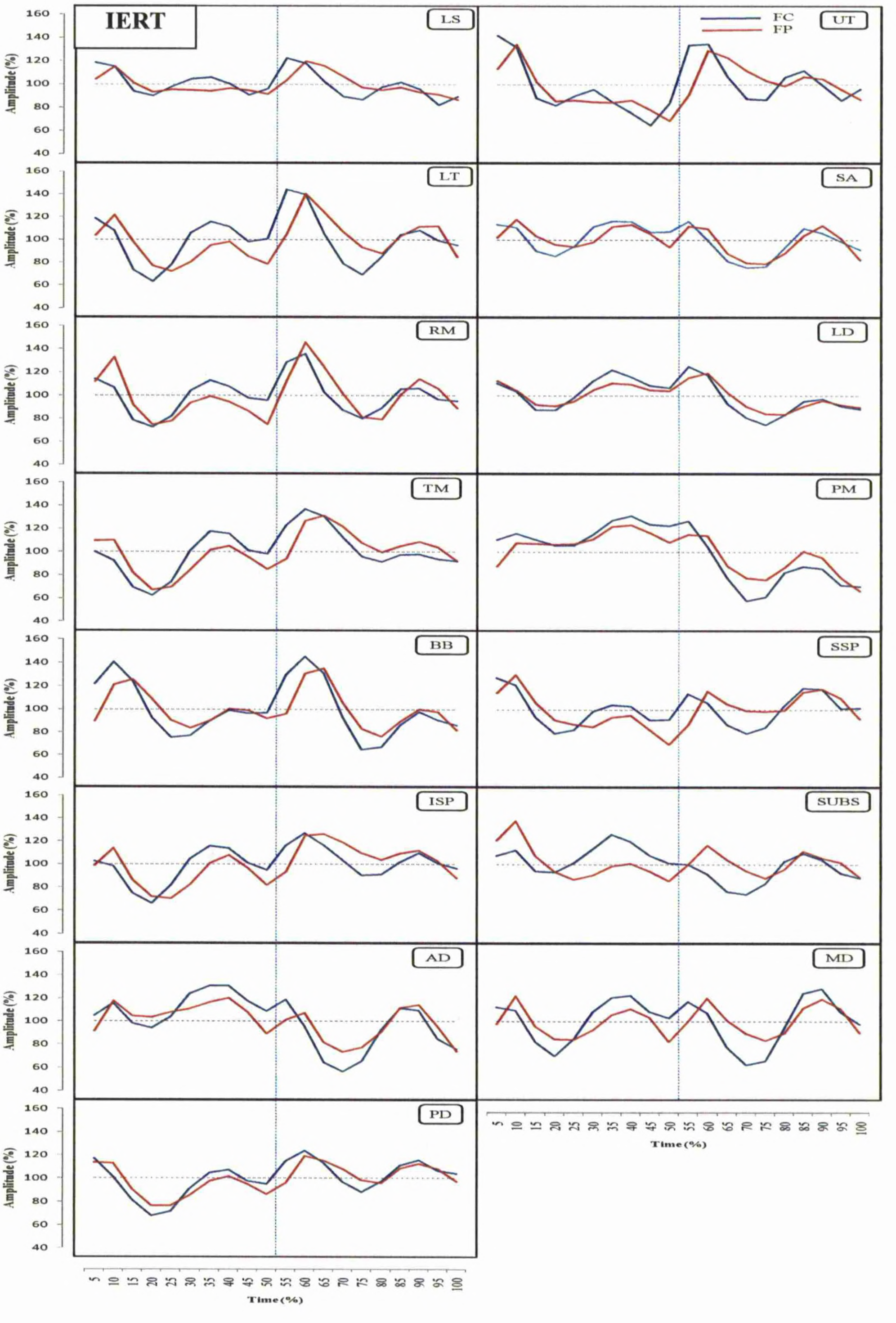


Figure 6 - 7: Comparing the activation pattern of 15 shoulder muscles between female controls (FC, blue line) and patients (FP, red line) during internal-external rotation task (IERT).

Table 6 - 4: Activation pattern differences in individual shoulder muscles within muscle groups as compared between female patients and controls during internal-external rotation task (IERT).

Bold blue p-values indicated significant difference with higher contribution in controls, while bold red p-values indicated higher contribution in patients.

Cycle		Phase (1) Internal rotation										Phase (2) External rotation									
	Muscle	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Scapular positioning	LS	0.20	1.00	0.38	0.46	0.79	0.15	0.12	0.69	0.51	0.57	**0.01**	0.69	0.06	**0.00**	**0.03**	0.73	0.86	0.97	**0.02**	0.73
	UT	**0.04**	0.57	0.25	0.90	0.83	0.16	0.66	0.25	0.10	0.10	**0.00**	0.48	0.31	**0.04**	**0.03**	0.76	0.86	0.51	0.15	0.24
	LT	0.24	0.17	**0.02**	0.25	0.43	**0.00**	**0.04**	0.07	0.24	**0.04**	**0.01**	0.93	0.12	**0.01**	**0.01**	0.79	0.86	0.86	0.12	0.19
	SA	0.17	0.32	0.29	0.31	0.93	**0.04**	0.29	0.60	0.43	**0.04**	0.48	0.14	0.36	0.43	0.52	0.36	0.25	0.36	0.76	0.17
	RM	0.70	0.14	0.19	0.79	0.28	0.21	0.30	0.55	0.36	0.13	0.11	0.48	0.14	0.25	0.91	0.21	0.30	0.66	0.79	0.59
Humeral Head Centring	LD	0.97	0.69	0.40	0.60	0.28	0.14	**0.02**	0.46	0.51	0.31	0.12	0.90	**0.05**	0.10	**0.03**	1.00	0.33	0.93	0.55	0.97
	TM	0.40	**0.04**	0.09	0.97	0.38	**0.04**	**0.03**	0.11	0.19	**0.02**	**0.01**	0.25	0.93	0.27	0.25	0.16	0.12	**0.02**	**0.02**	0.76
	PM	0.14	0.48	0.33	0.90	0.65	0.46	0.25	0.27	0.33	**0.05**	0.15	0.38	0.46	**0.02**	0.06	0.73	0.15	0.19	0.33	0.73
	BB	**0.02**	0.12	0.51	0.17	0.10	0.73	0.83	1.00	0.76	0.97	**0.05**	0.20	0.69	0.17	**0.04**	0.19	0.74	0.73	0.51	0.48
	SSP	0.46	0.23	0.48	0.57	0.31	0.14	0.46	0.38	0.24	**0.02**	**0.00**	0.16	0.10	0.07	0.10	0.38	0.54	0.93	0.17	0.22
	ISP	0.90	0.07	0.27	0.73	0.22	**0.01**	0.11	0.54	0.43	**0.03**	**0.03**	1.00	0.46	0.08	**0.03**	**0.04**	**0.05**	0.19	0.26	0.46
	SUBS	0.62	0.10	0.25	0.91	**0.05**	**0.02**	0.09	0.07	0.13	0.09	0.62	**0.03**	**0.01**	**0.01**	0.48	0.74	1.00	0.62	0.10	0.96
Deltoid	AD	0.27	0.54	0.46	0.27	0.69	**0.05**	0.10	0.22	0.07	**0.01**	0.12	0.17	0.27	0.19	0.16	0.93	0.69	0.57	0.12	0.73
	MD	0.12	0.31	0.27	0.15	0.97	**0.05**	0.17	0.36	0.51	**0.04**	0.10	0.16	**0.01**	**0.00**	**0.04**	0.81	0.19	0.25	0.79	0.46
	PD	0.38	0.12	0.15	0.43	0.48	0.38	0.51	0.25	0.66	0.07	**0.03**	0.54	0.69	0.11	0.07	0.90	0.69	0.50	0.83	0.31

The individual averaged curves of female participants were compared in Figure 6 - 7. Table 6 - 4 revealed the significant differences during the course of the IERT and to be considered in relevance to Figure 6 - 3 and Figure 6 - 6.

In preparation for the internal rotation when the hand was in contact with the shelf (early phase 1), the SP and HHC groups showed less contribution in female patients than controls [Figure 6 - 4A], which coincided with the significant lower contribution of the UT and BB [Table 6 - 4] early in phase 1 ($p<0.05$ at 5% interval). As the hand passed over the bridge and moved away from the neutral position, and in spite that the muscle groups showed increased contribution in both controls and patients [Figure 6 - 4A-C], but the female patients showed significant lower activity in LT, SA, LD, TM, ISP, SUBS, AD and MD ($p<0.05$, at 30% and 35% intervals) [Table 6 - 4]. By the end of phase 1 (internal rotation) several muscles in Table 6 - 4 showed significant lower contribution of individual muscles in female patients including LT, SA, TM, PM, SSP, ISP, AD and MD ($p<0.05$, at 50% interval). Those significant differences matched the muscle group difference at the same time interval [Figure 6 - 4].

Early in phase 2 and in agreement with significant muscle group differences noted in Figure 6 - 4, LS, UT, LT, TM, BB, SSP, ISP and PD showed significant difference due to lower contribution by patients ($p<0.05$, at 55% interval). Finally, there was a corresponding significant differences in muscle group about mid-phase of external rotation [Figure 6 - 4], LS, UT, LT, LD, PM, BB, ISP, SUBS and MD (p<0.05 to <0.01, at 70% and 75% intervals).

6.1.6 Patterns of Individual Muscle Groups in Male Participants

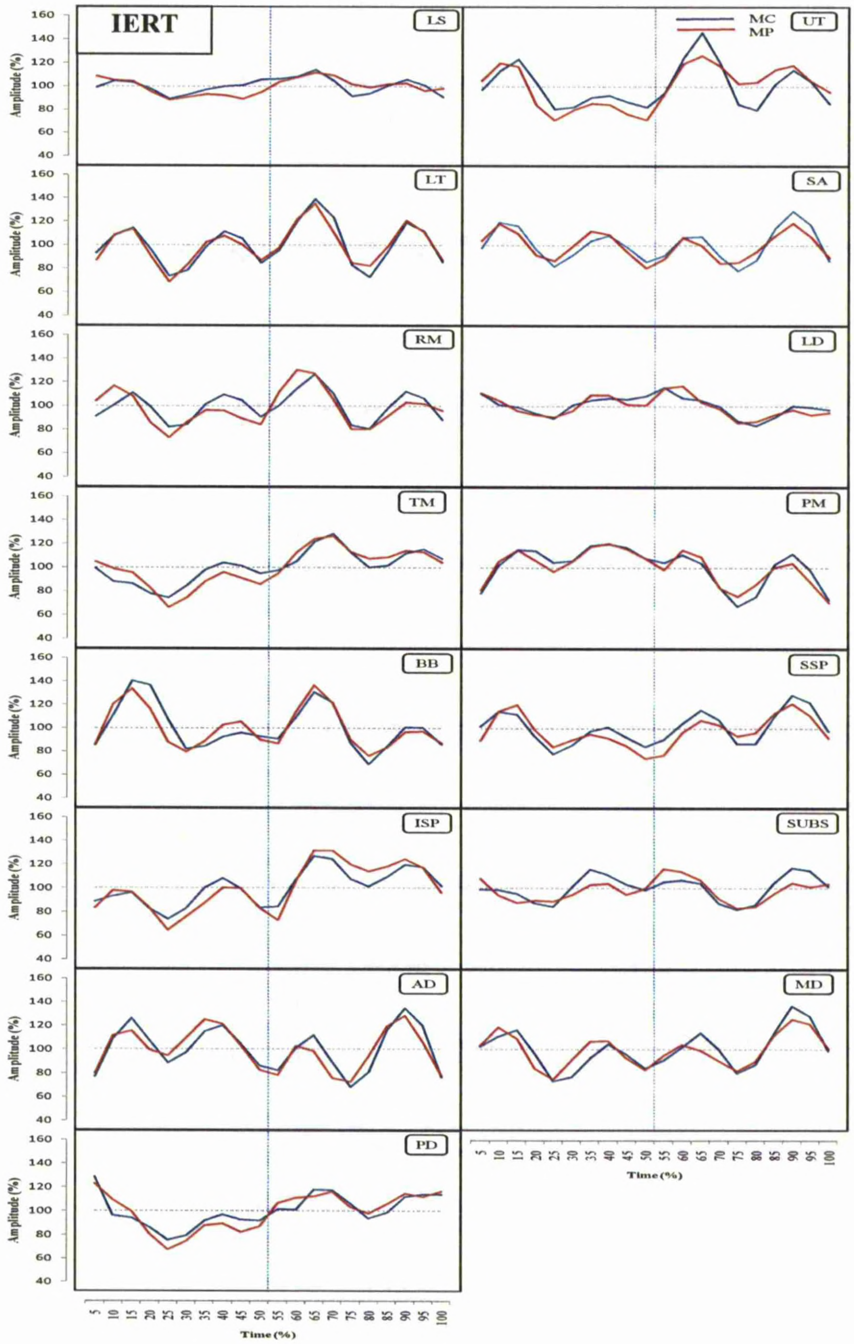


Figure 6 - 8: Comparing the activation pattern of 15 shoulder muscles between male controls (MC, blue line) and patients (MP, red line) during internal-external rotation task (IERT).

Table 6 - 5: Activation pattern differences in individual shoulder muscles within muscle groups as compared between male patients and controls during internal-external rotation task (IERT).

Bold blue p-values indicated significant difference with lower contribution in patients, while bold red p-values indicated higher contribution in patients.

Cycle		Phase (1) Internal rotation										Phase (2) External rotation									
	Muscle	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Scapular positioning	LS	0.15	0.97	0.73	0.64	0.80	0.97	0.36	**0.03**	**0.00**	**0.05**	0.82	0.68	0.57	0.22	**0.01**	0.25	0.80	0.51	0.25	0.27
	UT	0.61	0.85	0.78	0.23	0.27	0.82	0.64	0.23	0.30	0.27	0.92	0.51	0.21	1.00	**0.01**	**0.01**	0.23	0.36	0.66	0.51
	LT	0.78	0.80	0.96	0.66	0.49	0.57	0.41	0.59	0.41	0.90	1.00	0.97	0.68	0.75	0.95	0.21	0.80	0.80	0.27	0.85
	SA	0.51	0.73	0.72	0.61	0.64	0.31	0.25	0.61	0.64	0.57	0.59	0.97	0.39	0.53	0.43	0.21	0.47	0.22	0.06	0.82
	RM	0.77	0.72	0.92	0.12	0.45	0.77	0.72	0.23	0.14	0.45	0.47	0.23	0.82	0.64	0.87	0.62	0.31	0.18	0.55	0.84
Humeral Head Centring	LD	0.59	0.27	0.49	0.90	0.75	0.87	0.27	0.43	0.75	0.28	0.61	0.25	0.68	0.95	0.92	0.80	0.66	0.27	**0.04**	0.73
	TM	0.51	0.28	0.25	0.47	0.78	0.61	0.14	0.21	**0.03**	0.30	0.53	0.28	0.82	0.47	0.92	0.18	0.28	0.95	0.24	0.82
	PM	0.85	0.75	0.91	0.18	0.18	0.70	0.34	0.78	0.97	0.57	0.57	0.95	0.61	1.00	0.36	0.19	0.76	0.17	0.27	0.75
	BB	0.73	0.30	0.45	0.15	0.14	0.80	0.97	0.38	0.34	0.78	0.84	0.41	0.55	0.97	0.90	0.45	0.82	0.49	0.53	0.92
	SSP	0.43	0.80	0.47	0.47	0.59	0.75	0.97	0.16	0.25	0.47	0.17	0.41	0.19	0.27	0.95	0.11	0.47	0.73	0.39	0.66
	ISP	0.70	0.38	0.90	0.75	0.47	0.51	0.15	0.43	0.17	0.22	0.45	0.95	0.78	0.75	0.08	0.08	0.08	0.30	0.73	0.53
	SUBS	0.57	0.49	0.69	0.95	0.72	0.74	0.28	0.77	0.25	0.45	0.37	0.51	0.46	0.55	0.92	0.92	0.11	**0.02**	**0.05**	0.72
Deltoid	AD	0.73	0.95	0.43	0.87	0.49	0.15	0.22	0.80	0.92	0.73	0.68	0.70	0.47	0.31	0.73	0.15	0.61	0.47	**0.05**	0.78
	MD	0.87	0.43	0.57	0.49	0.67	**0.03**	**0.05**	0.53	0.97	0.95	0.80	0.85	0.15	0.45	0.57	0.72	0.95	0.45	0.73	0.70
	PD	0.97	0.22	0.68	0.73	0.61	0.79	0.68	0.30	0.08	0.43	0.97	0.41	0.53	0.78	0.78	0.30	0.41	0.68	0.57	0.64

In male patients, the muscle activation pattern either in muscle groups which showed no significant differences [Figure 6 - 6], or in individual muscles with very limited and sporadic significant differences [Table 6 - 5] ; there was an indication of the similarity of patterns between controls and patients in IERT.

6.1.7 Relative Muscle Activation Map in Female Controls and Patients (Qualitative Assessment)

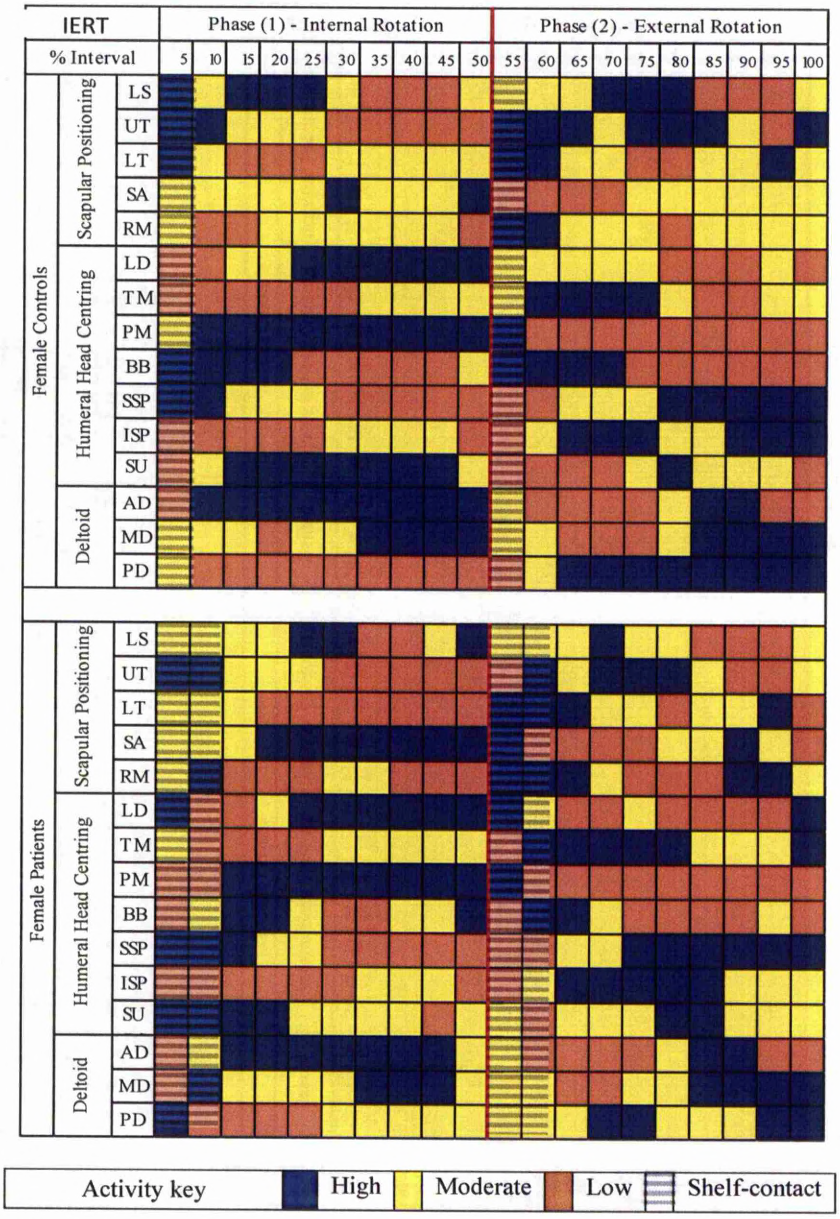


Figure 6 - 9: Qualitative assessment of muscle activation patterns in female groups during internal-external rotation task (IERT).

The relatively high activity included the highest 5 values, the relatively low activity included the lowest 5 values, and the relatively moderate activity included the remaining 5 values of mean amplitude % at every 5% interval of the time domain (for shelf-contact duration see Table 6 - 13).

The following table describes the individual muscle activation pattern of female controls during both phases of IERT, based on the relative activity of muscles in Table 6 - 6.

Table 6 - 6: Qualitative description of the ranked muscles of female controls during internal (IR)-external (ER) rotation task.

	Muscles	Phase 1 (IR)	Phase 2 (ER)	Remarks
Scapular Positioning	LS	Mostly high activity in first half and mostly low in second half.	Early moderate, mid-range high and mostly low activity to end	High activity with shoulder elevation to move over the bridge in both phases
	UT	High activity since the start, moderate to end of first half and low activity in second half	Mostly high activity	High to moderate activity in first half of IR and mostly high with ER related to shoulder elevation
	LT	Started high activity by dropped mostly to low in first half, then recovered to moderate in second half	Early high activity, gradual decline to low at mid-phase, then mostly with moderate activity	Controlling scapular medial rotation (protraction) in second half of IR. Early high activity with ER matched with UT and RM (balanced effect). In phase 1, its activity was reversed as compared with LS and UT
	SA	Moderate activity was predominant all through	Low activity in first half then moderate in the second	Moderately active with IR helps scapular protraction. The moderate activity in second half of ER allowed scapular ER and control retraction
	RM	Mostly moderate activity all through	Early high activity then maintained moderate activity.	A medial stabilizer of scapula during internal rotation, and scapular retractor in preparation for ER
Humeral head Centring	LD	Gradual increase toward mid-phase then maintained high activity to the end	Moderate activity in first half and mostly low activity in the second half	Internal Rotator (60%) after passing the bridge. Eccentric moderate activity with first half of ER
	TM	Almost low activity in first half and moderate in second half	Mostly high activity in first half and alternate between moderate and low in the second half.	Moderately active with late IR, but also highly active in early ER (eccentric/extension element)
	PM	High activity through the whole phase	Low activity	Internal Rotator (90%). Low activity through ER
	BB	Mostly high activity in first half and low activity in the second	Similar pattern to phase 1	The high activity in early both phases matched the elbow flexion to move the hand over the bridge
	SSP	Early high activity and decreased gradually to mid-phase and further lower activity to end	Exactly opposite contribution to that in phase 1	It is a late external rotator (50%). The early high activity with IR reflected abduction and eccentric response to reversed motion
	ISP	Low activity in first half and moderate in the second half	Mostly high active	A highly active external rotator (60%). Moderate activity in late IR reflected eccentric stabilizing effect
	SUBS	Mostly high activity	Mostly low activity	Following PM, acting as internal rotator (70%) in this group
Deltoid	AD	Mostly high activity through the phase	Mostly low activity with a short high activity in second half	The most active internal rotator (90%) in this group, similar to PM in previous group
	MD	Moderate to high contribution	Low, moderate to high contribution	Late high activity in both phases associated with slight abduction
	PD	Mostly low contribution	Mostly high contribution	External rotator (80%)

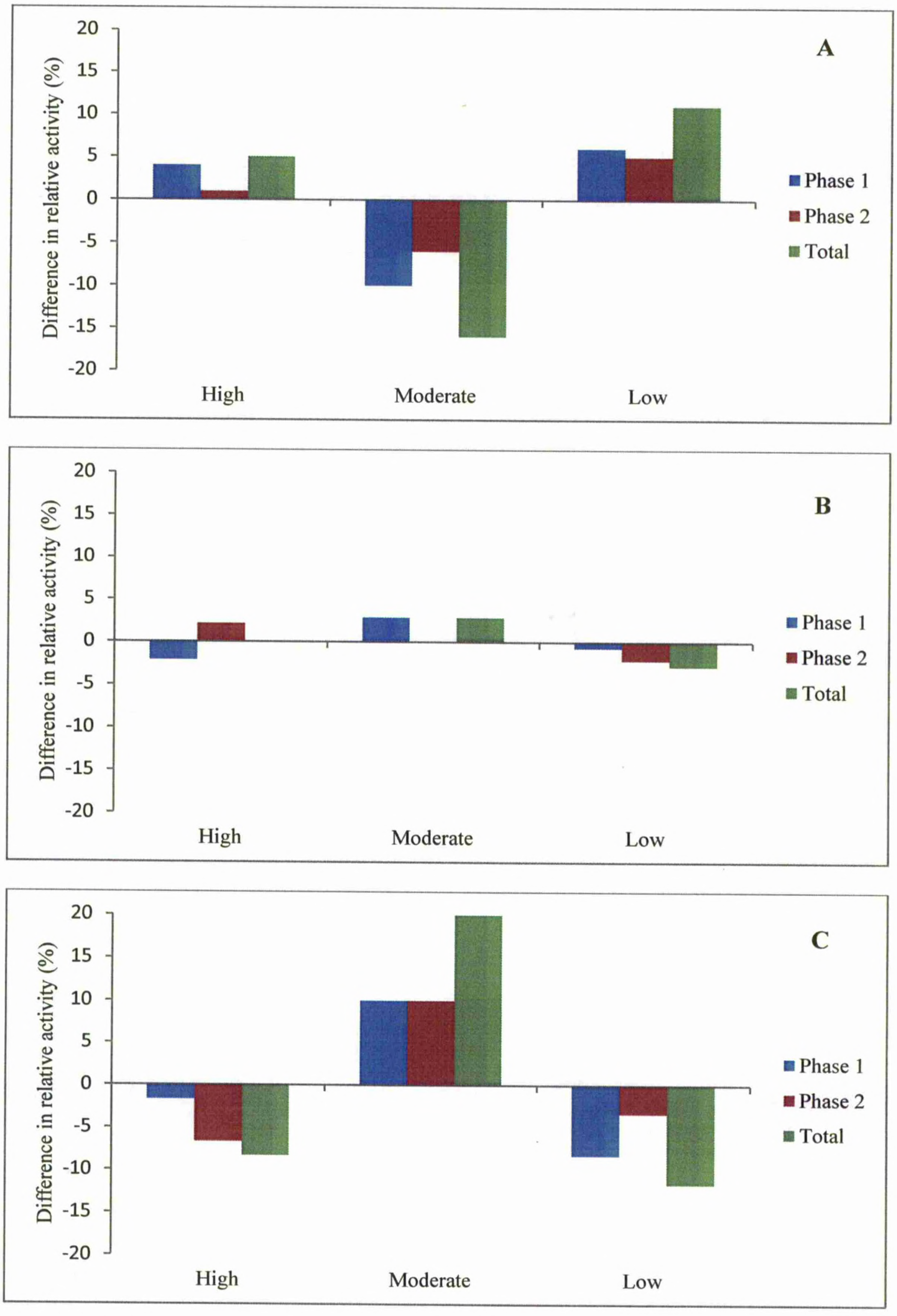


Figure 6 - 10: The percentage difference of the relative activity between female groups during internal-external rotation task (IERT).

(A) Scapular positioning muscle group, (B) Humeral head centring group and (C) Deltoid

6.1.7.1 Scapular Positioning in Female Patients Compared to Controls

The relatively high activity was increased in patients by 4% in phase 1 and 1% in phase 2, the relatively moderate activity was reduced in phase 1 by 10% and 6% in phase 2, and the relatively low activity increased in phase 1 by 6% and phase 2 by 4%. [Figure 6 - 10A]. Major changes in relative muscle activity were detected in LT and SA only. LT showed reduced activity in second half of internal rotation, while SA demonstrated high activity in the last 70% of internal rotation. Other muscles as LS and RM showed slight difference with short compensatory effect. UT of patients was a mirror image to that of controls during internal rotation, but with external rotation there was minor reduction probably due to timing shift to left [Figure 6 - 9].

6.1.7.2 Humeral Head Centring in Female Patients Compared to Controls

The relatively high activity decreased and increased by 2% in phase 1 and phase 2, respectively; the relatively moderate activity increased by 3% in phase 1 only, and the relatively low activity decreased by 1% and 2% in phase 1 and 2, respectively [Figure 6 - 10B]. The important changes in the HHC group were observed in SUBS and BB. SUBS showed higher activity than that of controls in the first half of both internal and external rotation but to a lower level in the second half of internal rotation. BB started with lower activity and finished the first phase with higher activity than in controls. TM and ISP appeared as mirror images to those in controls during internal rotation and first half of external rotation. Later, TM showed increased activity while ISP showed fluctuated activity different from controls. Though it showed evidence of strong mirror image during external rotation when the activity was low, PM also reflected similar high activity to controls during internal rotation except in the first interval of that phase. This finding was probably due to delay in onset of activity. Other muscles demonstrated mirror imaging through both phases to a large extent [Figure 6 - 9].

6.1.7.3 Relative Muscle Activity Alterations in Deltoid of Female Patients

The relatively high activity decreased by 2% and 7% in phase 1 and 2,respectively; the relatively moderate activity increased by 10% in both phases, and the relatively low activity decreased by 8% and 3% in phase 1 and 2, respectively [Figure 6 - 10C].

No major changes were observed in AD and MD, while PD showed obvious changes in both phases. The activity was increased in the second half of internal rotation while it decreased in the second half of external rotation [Figure 6 - 9].

6.1.8 Relative Muscle Activation Map in Male Controls and Patients (Qualitative Assessment)

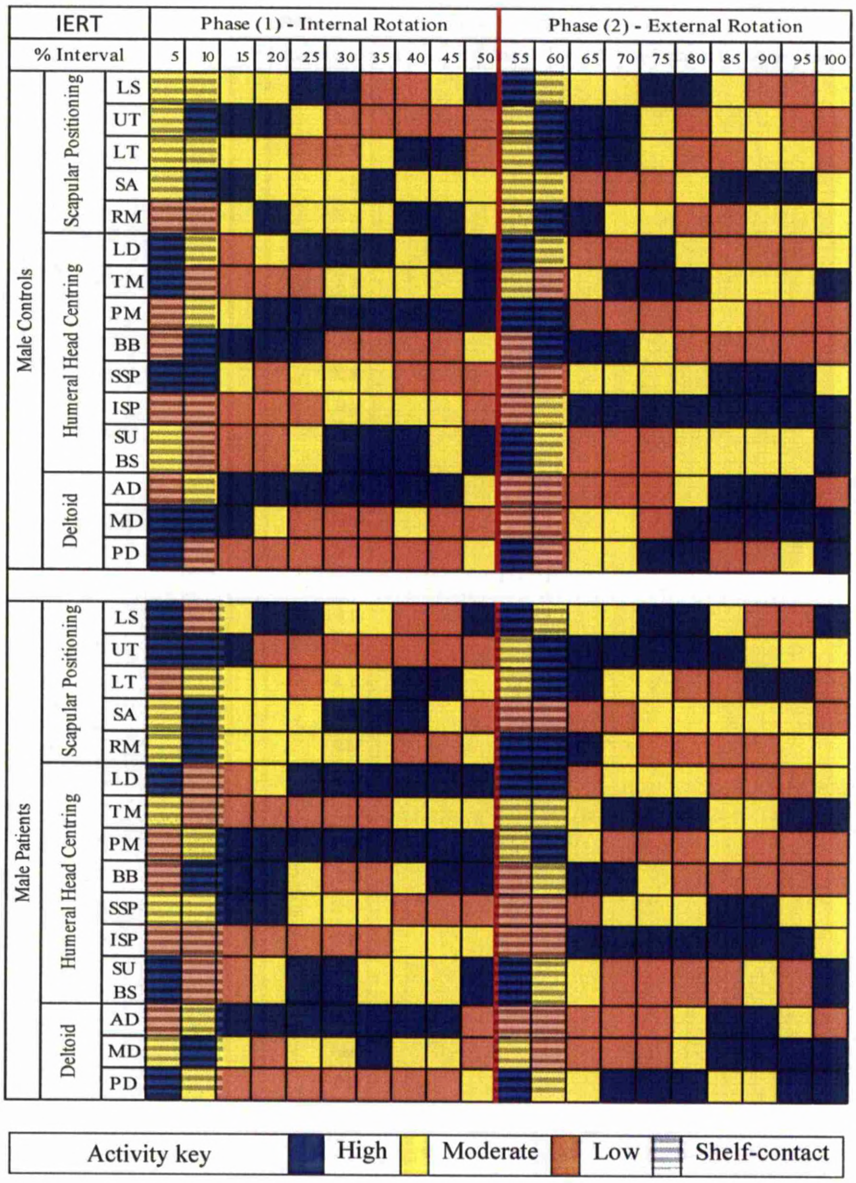


Figure 6 - 11: Qualitative assessment of muscle activation patterns in male groups during internal-external rotation task (IERT).

The relatively high activity included the highest 5 values, the relatively low activity included the lowest 5 values, and the relatively moderate activity included the remaining 5 values of mean amplitude % at every 5% interval of the time domain (for shelf-contact duration see Table 6 – 13).

The following table describes the individual muscle activation pattern of male controls during both phases of IERT, based on the relative activity of muscles in Figure 6 - 11.

Table 6 - 7: Qualitative description of the ranked muscles of male controls during internal-external rotation task (IERT).

	Muscles	Phase 1 (IR)	Phase 2 (ER)	Remarks
Scapular Positioning	LS	Moderate activity in first half, high about mid-phase and increased from low to high in second half.	Mostly moderate activity in first half, high about mid-phase, and fluctuated (moderate-low-moderate) activity in second phase.	Moderate to high activity with shoulder elevation to move over the bridge in both phases
	UT	Mostly high activity in first half, and complete low activity in second half	Mostly high activity in first half and fluctuated (low-moderate-low) in second half	High activity in first half of both IR and ER related to shoulder elevation (Proportional level of activity as compared with LS).
	LT	Mostly moderate activity in first half, low about mid-range, and mostly high to end	Mostly high activity in first half and fluctuated (moderate-low) in second half	With IR, the eccentric control increased and only dropped when the arm about neutral position. It showed balancing pattern with UT
	SA	Mostly moderate activity through the phase with short high activity in each half	Mostly low activity in first half and high in second half	Moderate to high activity with IR allowed scapular protraction. The moderate to high activity with ER allowed scapular ER and control retraction
	RM	A start of low activity then fluctuate between moderate and high to the end	Moderate to high in first half and mostly moderate in second half	A moderately active medial stabilizer of scapula during IR with eccentric control. Concentric control during ER
Humeral head Centring	LD	Fluctuated activity in first half, but mostly high in second half	Fluctuated activity in first half and mostly low in second half	Internal Rotator (60%) after passing the bridge (mid-range). Mostly low activity with ER
	TM	Mostly low activity in first half and moderate in second half	High activity about mid-phase , then moderate and high at end	Moderately active with late IR, but also highly active in early ER (eccentric/extension element)
	PM	Mostly high activity to end	Mostly low activity through the phase	Internal Rotator (70%). Mostly low activity through ER
	BB	Mostly high activity in first half and low activity in the second	Similar pattern to phase 1	The high activity in early both phases matched the elbow flexion to move the hand over the bridge
	SSP	Early high activity, mid-phase moderate and late low activity	Exactly opposite to activity order in phase 1 (low, moderate and finally high)	External rotator in late range. The early high activity with IR reflected abduction and eccentric response
	ISP	Low activity in first half and moderate in the second half	Mostly high active	A highly active external rotator (80%), with moderate eccentric activity with late IR for stability
	SUBS	Mostly low activity in first half and high in second half	Mostly low activity in first half and moderate in second half	Next to PM, acting as an internal rotator in this group
Deltoid	AD	Mostly high activity through the phase	Low activity in first half and mostly high in second half	The most active internal rotator (70%) in this group, similar to PM in previous group
	MD	Early high activity then mostly moderate to end	High activity in second half	High activity with initial IR and late ER.
	PD	Predominant low activity	Fluctuated activity (high-low-moderate)	Participating in external rotation

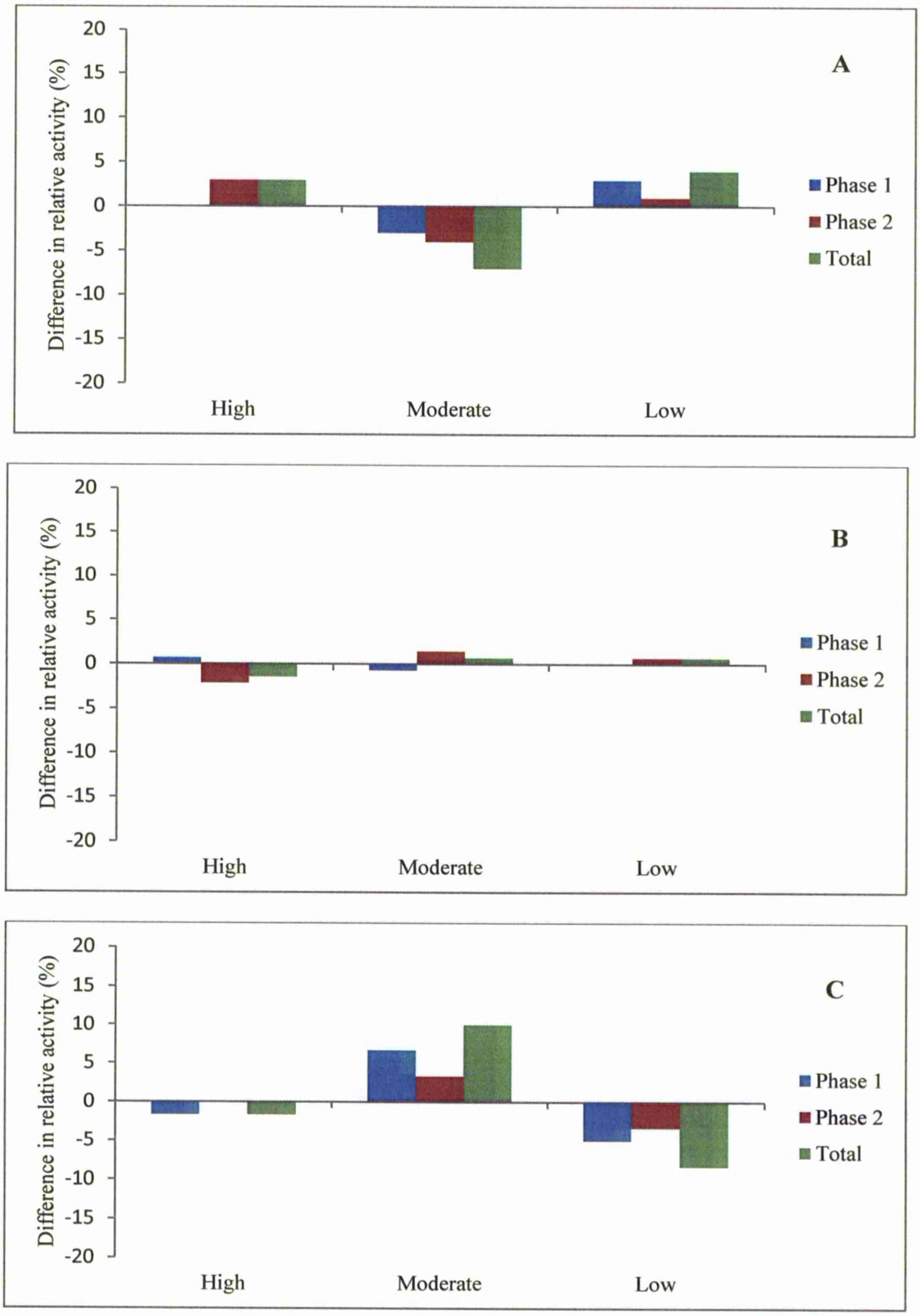


Figure 6 - 12: The percentage difference of the relative activity between male groups during internal-external rotation task (IERT).

(A) Scapular positioning muscle group, (B) Humeral head centring group and (C) Deltoid

6.1.8.1 Scapular Positioning in Male Patients

The relatively high activity was increased in patients by 3% in phase 2, the relatively moderate activity was reduced by 3% in phase 1 and 4% in phase 2, and the relatively low activity increased in phase 1 by 3% and phase 2 by 1%. [Figure 6 - 12A]. Generally, there were no major changes when comparing the pattern based on the relative activity of muscles comprising the SP group during IERT. The muscles reflected very similar pattern except for few changes in SA and RM. In patients, SA showed increased activity with later internal rotation and decreased activity with external rotation, while RM showed decreased activity in both rotations [Figure 6 - 11].

6.1.8.2 Humeral Head Centring in Male Patients

The relatively high activity decreased by 1% in phase 1 and reduced by 2% in phase 2, the relatively moderate activity decreased by 1% in phase 1 and increased by 1% in phase 2, and the relatively low activity increased by 1% in phase 2 [Figure 6 - 12B]. In the HHC group of patients, all incorporated muscles had mirror image to the controls and the altered muscle was the SUBS. SUBS showed decreased activity in the second half of both internal and external rotations [Figure 6 - 11].

6.1.8.3 Deltoid Activity Alterations in Male Patients

The relatively high activity decreased by 2% only in phase 1, the relatively moderate activity increased by 7% in phase 1 and 3% in phase 2, and the relatively low activity decreased by 5% and 3% in phase 1 and 2, respectively [Figure 6 - 12C]. Finally, the deltoid components revealed no pattern difference in AD, while MD had reduced activity in both phases and PD had reduced activity only in phase 2 of IERT [Figure 6 - 11].

6.2 Waist-Up Task

The WUT was designed to test loaded forward elevation and lowering (concentric and eccentric) activity between a lower shelf placed at the waist level and a higher shelf placed 25 cm above the lower shelf. The test was performed as previously described in methods chapter (chapter 3 – Material and Methods: section 3.6.8.3). The WUT tested the mobility of shoulder within a range lower than the range of painful arc in patients with SIS. Therefore, the majority of patients were able to perform the task with minimal or no pain. The following results were reported from 10 averaged mid- cycles during the task.

WUT: Phase (1) Arm elevation	WUT: Phase (2) Arm lowering
Duration = one second	Duration = one second

Figure 6 - 13: Waist-up task (WUT).

It involves moving a load of 1 kg between a lower shelf placed at the waist level and a higher shelf 25 cm above the waist level. A cycle composed of two phases. Phase (1) included contact lower shelf and moving upwards within one second. Phase (2) included contact higher shelf and moving downwards back to the start point on the lower shelf within another second.

6.2.1 Cycle Duration

The average duration of 10 cycles was determined as the time length of shelf-contact and off-shelf time during arm elevation (phase1) and arm lowering (phase2) of the WUT. Table 6 - 1 presents and compares the percentage of shelf-contact and off shelf time in each phase for both female and male groups.

Table 6 - 8: Comparing the time % of the phase components (shelf-contact and off-shelf) within female (subacromial impingement syndrome (SIS) patients, n=16; controls, n=13) and male (SIS patients, n=17; controls, n=20) subjects during waist-up task (WUT). Bold *p* values are less than 0.05.

Group	WUT	Phase (1) Arm elevation					Phase (2) Arm lowering				
		SIS Patients		Controls		*p* value	SIS Patients		Controls		*p* value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female	Shelf-Contact	12.5	5.7	7.4	2.7	**0.01**	12.2	5.5	7.3	2.2	**0.01**
	Off-Shelf	37.5	5.5	42.5	2.5	**0.01**	37.8	5.6	42.9	2.4	**0.01**
Male	Shelf-Contact	10.2	3.7	11.9	4.6	0.38	11.5	3.8	12.3	5.12	0.34
	Off-Shelf	38.8	3.9	37.8	4.4	0.48	39.6	3.8	38.1	5.4	0.34

In relation to the female groups, the mean duration of shelf-contact was significantly higher while the off-shelf was significantly lower in SIS patients compared to the controls in both phases ($p<0.01$). Concerning the male groups, there was no significant difference between shelf-contact and off-shelf duration, however, there was a trend towards lower shelf-contact and longer off-shelf duration in patients for both phases. These findings were in contrast to those reported in female groups.

6.2.2 Mean Amplitude

The normalized mean amplitude of phase 1 and phase 2 was used to perform intra-group and inter-group comparisons during the WUT [Table 6 – 10 and Table 6 – 9]

In female patients and controls, intra-group comparisons of phase 1 and phase 2 mean amplitude %, revealed a significant differences for all muscles [Table 6 – 9].

In male groups, a matched highly significant difference was found for all muscles except the PD [Table 6 – 9].

Inter-groups differences for each phase were only significant between female groups for SSP in phase 1 and ISP in phase 2 [Table 6 – 10].

Table 6 - 9: Normalized mean amplitude (%) comparison between phase 1 and phase 2 in female (subacromial impingement syndrome (SIS) patients=16, controls=13) and male (SIS patients= 18, controls=19) subjects during waist-up task (WUT). Bold p values are less than 0.05.

Muscle Groups	Muscle	SIS Patients					Controls				
		Phase 1		Phase 2		p value	Phase 1		Phase 2		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular	LS	109.1	7.8	91.2	7.8	**0.00**	112.3	5.9	88.1	7.0	**0.00**
	UT	108.2	6.4	92.3	7.1	**0.00**	112.0	3.4	88.2	5.7	**0.00**
	LT	109.0	4.7	91.6	4.9	**0.00**	109.3	6.2	90.3	7.5	**0.00**
	SA	114.6	12.9	86.5	13.1	**0.00**	118.1	10.5	81.3	10.3	**0.00**
	RM	123.9	17.2	77.4	17.2	**0.00**	124.4	11.0	74.5	12.6	**0.00**
Humeral Head Centring	LD	113.4	12.8	87.1	12.5	**0.00**	118.0	8.1	82.5	8.9	**0.00**
	TM	104.7	5.2	95.7	4.9	**0.01**	106.0	3.3	93.8	5.1	**0.00**
	PM	106.4	6.4	94.8	6.8	**0.01**	107.5	3.9	92.8	4.2	**0.00**
	BB	106.0	4.2	95.0	4.5	**0.00**	108.3	6.1	91.3	7.9	**0.00**
	SSP	106.5	5.7	94.0	5.8	**0.00**	107.8	3.5	91.9	4.4	**0.00**
	ISP	104.2	4.5	96.8	4.9	**0.01**	106.8	4.5	92.2	6.0	**0.00**
	SUBS	116.7	9.8	84.3	9.9	**0.00**	109.0	8.3	90.8	7.3	**0.00**
Deltoid	AD	107.2	5.4	94.2	5.5	**0.00**	110.5	4.5	89.3	4.5	**0.00**
	MD	103.5	5.4	96.8	5.0	**0.02**	104.1	5.3	96.3	6.3	**0.04**
	PD	110.7	11.4	88.5	11.8	**0.00**	110.3	10.5	89.5	11.0	**0.01**
Male Group											
Scapular	LS	104.9	5.7	96.1	6.2	**0.00**	106.3	8.3	94.5	8.4	**0.01**
	UT	104.0	6.4	96.6	6.6	**0.01**	106.6	6.7	93.4	6.7	**0.00**
	LT	106.9	5.3	93.6	5.1	**0.00**	105.6	5.9	94.3	6.5	**0.00**
	SA	111.9	10.3	88.9	10.9	**0.00**	111.5	12.0	88.7	12.0	**0.00**
	RM	119.8	20.9	81.5	21.7	**0.00**	121.5	14.3	78.9	14.0	**0.00**
Humeral Head Centring	LD	111.8	8.9	89.1	8.7	**0.00**	110.7	9.2	89.8	9.6	**0.00**
	TM	103.4	3.9	97.0	4.1	**0.00**	104.4	4.5	95.6	4.3	**0.00**
	PM	106.4	5.7	94.8	5.1	**0.00**	104.5	7.1	96.5	7.3	**0.01**
	BB	107.5	7.1	93.6	7.9	**0.00**	108.1	10.4	92.5	10.6	**0.00**
	SSP	106.6	5.9	94.5	6.4	**0.00**	105.3	6.3	95.1	6.5	**0.00**
	ISP	105.4	9.0	96.2	10.3	**0.00**	106.1	6.7	94.7	6.9	**0.00**
	SUBS	110.7	8.8	90.0	8.9	**0.00**	109.2	12.8	91.7	13.8	**0.01**
Deltoid	AD	108.4	6.5	92.8	6.1	**0.00**	104.3	7.1	96.7	7.3	**0.02**
	MD	103.9	9.1	95.9	8.1	0.10	103.6	5.6	96.7	5.2	**0.03**
	PD	106.2	10.2	94.1	10.0	**0.01**	103.3	8.2	96.9	8.9	0.08

Table 6 - 10: Normalized mean amplitude (%) comparison within female (subacromial impingement syndrome (SIS) patients=16, controls=13) and male (SIS patients = 18, controls =19) subjects during phases 1 and 2 of the waist-up task (WUT). Bold p values are less than 0.05.

Muscle Groups	Muscle	Phase 1 Mean Amplitude%					Phase 2 Mean Amplitude%				
		SIS Patients		Control		p value	SIS Patients		Control		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular	LS	114.6	12.9	118.1	10.5	0.38	86.5	13.1	81.3	10.3	0.22
	UT	123.9	17.2	124.4	11.0	0.83	77.4	17.2	74.5	12.6	0.73
	LT	113.4	12.8	118.0	8.1	0.09	87.1	12.5	82.5	8.9	0.08
	SA	106.0	4.2	108.3	6.1	0.27	95.0	4.5	91.3	7.9	0.24
	RM	110.7	11.4	110.3	10.5	0.96	88.5	11.8	89.5	11.0	0.89
Humeral Head Centring	LD	104.7	5.2	106.0	3.3	0.29	95.7	4.9	93.8	5.1	0.29
	TM	106.4	6.4	107.5	3.9	0.69	94.8	6.8	92.8	4.2	0.33
	PM	106.5	5.7	107.8	3.5	0.22	94.0	5.8	91.9	4.4	0.15
	BB	104.2	4.5	106.8	4.5	0.12	96.8	4.9	92.2	6.0	0.07
	SSP	116.7	9.8	109.0	8.3	**0.04**	84.3	9.9	90.8	7.3	0.08
	ISP	107.2	5.4	110.5	4.5	0.16	94.2	5.5	89.3	4.5	**0.04**
	SUBS	103.5	5.4	104.2	5.3	0.61	96.8	5.0	96.3	6.3	0.64
Deltoid	AD	109.1	7.8	112.3	5.9	0.33	91.2	7.8	88.1	7.0	0.43
	MD	108.2	6.4	112.0	3.4	0.10	92.3	7.1	88.2	5.7	0.11
	PD	109.0	4.7	109.3	6.2	0.76	91.6	4.9	90.3	7.5	0.84
Male Group											
Scapular	LS	111.9	10.3	111.5	12.0	0.87	88.9	10.9	88.7	12.0	0.93
	UT	119.8	20.9	121.5	14.3	0.96	81.5	21.7	78.9	14.0	0.93
	LT	111.8	8.9	110.7	9.2	0.63	89.1	8.7	89.8	9.6	0.63
	SA	107.5	7.1	108.1	10.4	0.87	93.6	7.9	92.5	10.6	0.96
	RM	106.2	10.2	103.3	8.2	0.78	94.1	10.0	96.9	8.9	0.80
Humeral Head Centring	LD	103.4	3.9	104.4	4.5	0.34	97.0	4.1	95.6	4.3	0.26
	TM	106.4	5.7	104.5	7.1	0.48	94.8	5.1	96.5	7.3	0.74
	PM	106.6	5.9	105.3	6.3	0.34	94.5	6.4	95.1	6.5	0.65
	BB	105.4	9.0	106.1	6.7	0.80	96.2	10.3	94.7	6.9	0.84
	SSP	110.7	8.8	109.2	12.8	0.84	90.0	8.9	91.7	13.8	0.67
	ISP	108.4	6.5	104.3	7.1	0.09	92.8	6.1	96.7	7.3	0.14
	SUBS	103.9	9.1	103.6	5.6	0.82	95.9	8.1	96.7	5.2	0.96
Deltoid	AD	104.9	5.7	106.3	8.3	0.78	96.1	6.2	94.5	8.4	0.74
	MD	104.0	6.4	106.6	6.7	0.35	96.6	6.6	93.4	6.7	0.26
	PD	106.9	5.3	105.6	5.9	0.57	93.6	5.1	94.3	6.5	0.91

6.2.3 Muscle Activation Patterns during Waist-Up Task

EMG recordings during dynamic standardised movements of arm elevation and lowering task in healthy subjects and patients allowed the identification of patterns of muscle activity. The pattern was evident in an averaged curve 'ensemble curve' obtained from 10 cycles, which was time normalized (time %) and the magnitude was normalized to mean amplitude of each phase (mean amplitude %).

The normalized time % scale was further divided to 5% intervals and the normalized amplitude was averaged for each interval to obtain 20 mean normalized amplitude values (i.e. reducing 100 data points to 20 data points) (Chapter 3 – Material and methods: section 3.6.12). Finally, 20 values of mean amplitude % were available for the following comparisons: (1) muscle activation patterns for muscle groups, (2) muscle activation of individual muscles within muscle groups, and (3) qualitative comparisons of the ranked individual muscles at every 5% interval.

6.2.4 Muscle Activation Patterns for Muscle Groups during Waist-Up Task

6.2.4.1 Patterns of Muscle Groups in Female Participants

In female controls, the SP muscle group was the primary contributor to the arm elevation, which was then immediately followed by the deltoid group. As the hand left the lower shelf and moved upwards, all groups increased their activity together with the deltoid that was leading the activity followed by the HHC group and then lastly the SP group. From the mid-phase of elevation, after a short plateau, the three groups fired up more in the same order of the very beginning to reach a peak at mid-point of 40% interval, and then declined as the arm approached the higher shelf. During contact with the higher shelf, both SP and HHC groups showed brief plateau prior to a sharp decline. In early phase 2 and initial lowering of the arm, the HHC group led the movement, followed by the deltoid then SP groups. This order was maintained until the end of phase 2. Finally, the three groups showed a second peak in late phase 2 at the mid-point of 85% interval [Figure 6 - 14].

In female patients, the muscle activity of all muscle groups was lower than in controls at the start of the cycle with the SP group showing the lowest activity ($p<0.05$). During early arm elevation, SP group showed steep increase in activity and led the groups until the peak at mid-point of 45% interval. HHC and deltoid groups showed concomitant increase and repeated inter-change in level until the peak point. The peak was higher in controls showing a significant difference for HHC group (p=0.02, at 45% interval). Early in phase 2, the muscle groups in patients showed a higher level of activity than controls, particularly for the SP and deltoid groups (p<0.05, at 65% interval). Although there was a greater decline for the SP group during late phase 2, the activity pattern was similar in patients and controls. Time delay was observed for all muscle groups in patients [Figure 6 - 17 and Figure 6 - 21].

Female Controls

Female Patients

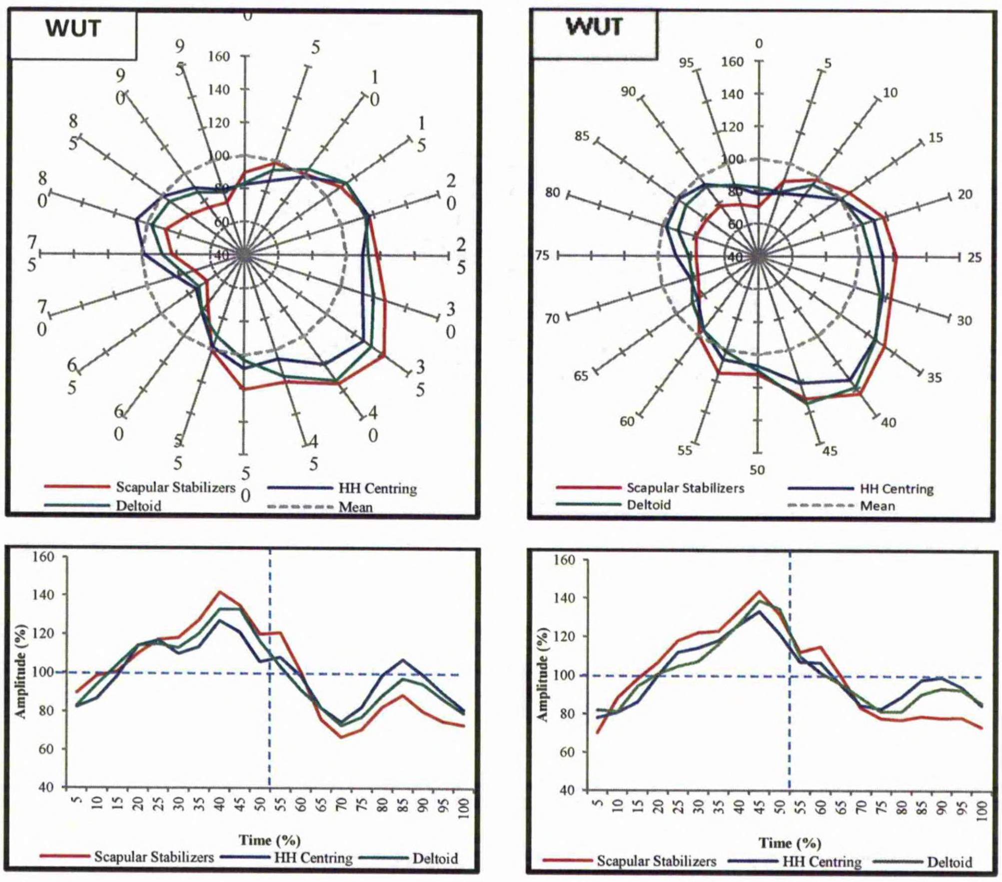
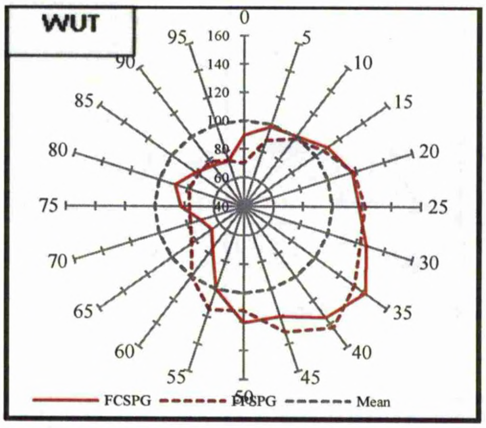
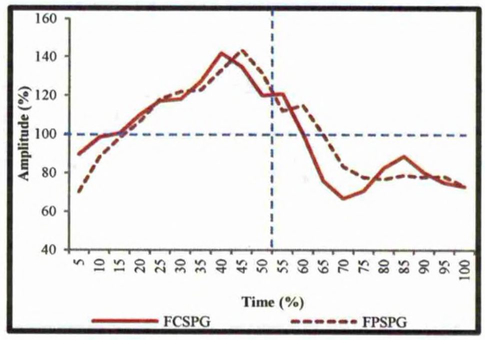


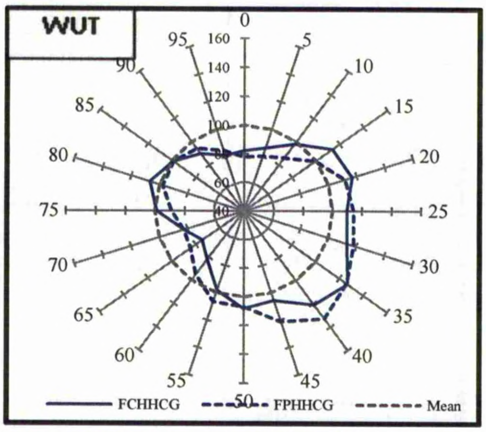
Figure 6 - 14: Activation patterns of shoulder muscle groups during waist-up task (WUT).

The scapular positioning, (LS, UT, LT, SA and RM), humeral head centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) groups in female controls (left) and female impingement patients (right).

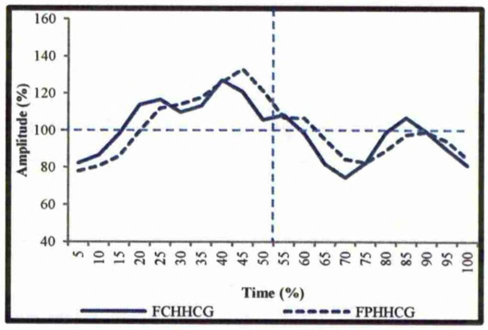


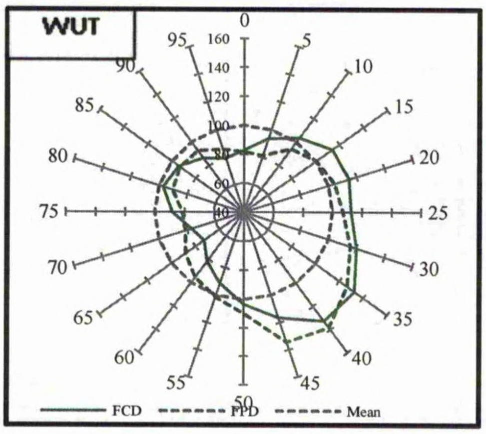
(A) Pooled scapular positioning muscles of female controls vs. female patients



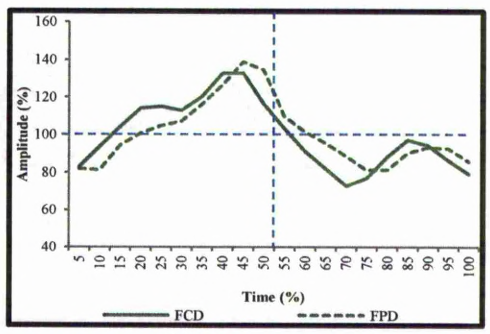


(B) Pooled humeral head centring muscles of female controls vs. female patients.





(C) Deltoid muscle of female controls vs. female patients.



%	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(A)	**0.03**	0.14	0.76	0.46	0.79	0.66	0.51	0.41	0.43	0.17	0.36	0.15	**0.02**	0.11	0.73	0.31	0.06	0.69	0.73	0.86
(B)	0.38	0.27	0.06	**0.01**	0.43	0.27	0.11	0.90	**0.02**	**0.03**	0.63	0.20	0.09	0.31	0.48	0.08	0.11	0.93	0.35	0.29
(C)	0.81	0.11	0.51	0.34	0.22	0.36	0.29	0.13	0.57	0.11	0.63	0.07	**0.04**	**0.04**	0.41	0.28	0.32	0.93	0.46	0.25

Figure 6 - 15: Comparing muscle groups between female controls (FC-) and patients (FP-) during waist-up task (WUT).

The statistical difference (*p* values) at every 5% interval of (A) Scapular Positioning, (B) Humeral head centring, and (C) Deltoid muscle. Bold values are statistically significant (p<0.05).

6.2.4.2 Activation Patterns of Muscle Groups in Male Participants

In male controls, the start point of the deltoid was in advance of the other two; but as soon as the arm attempted to move upwards, the SP group shot up leading the other two groups. It was followed by the deltoid and HHC group. Interestingly, simultaneous acute rise of both SP and HHC groups was observed with initial arm elevation. It was also interesting to see two peaks in phase 1. SP and HHC groups reached the first peak simultaneously at 25% interval, while the deltoid peak appeared at a lower level. The second peak (mid-point of 45% interval) was highest for SP group, followed by the deltoid and HHC groups [Figure 6 - 16].

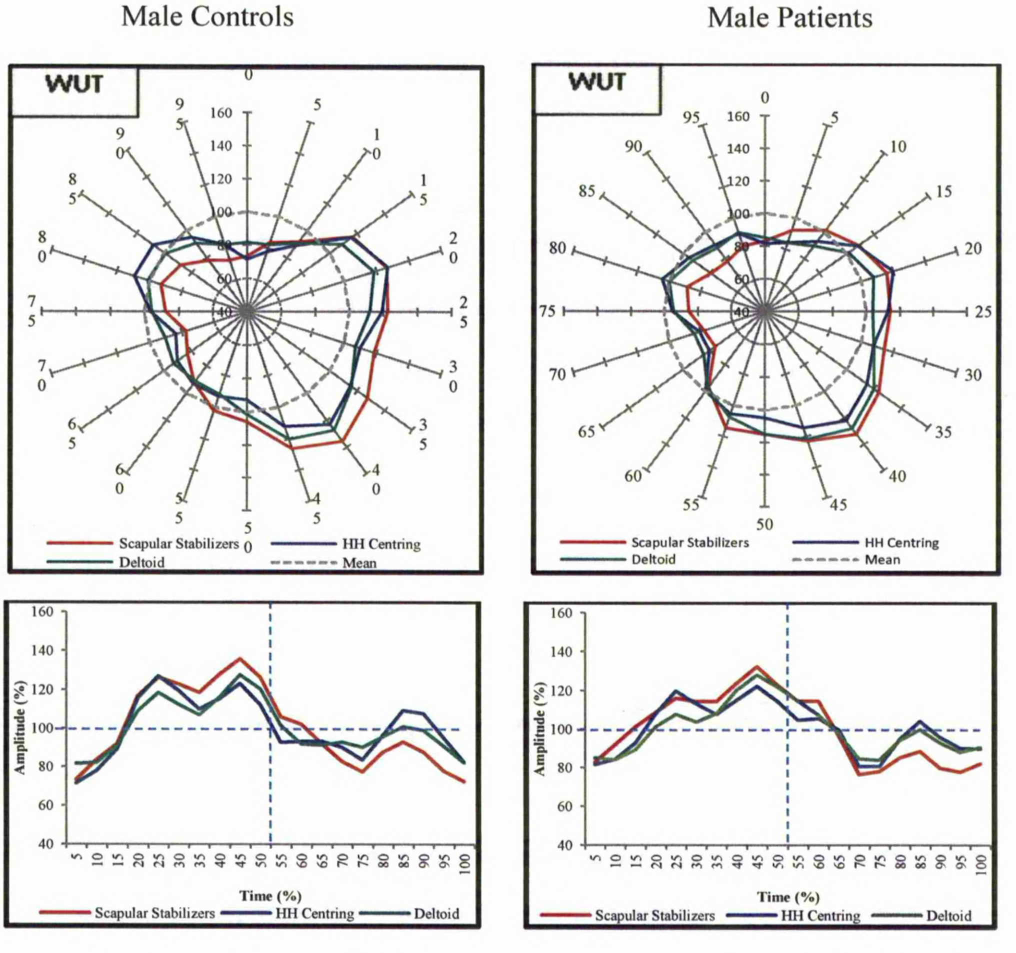
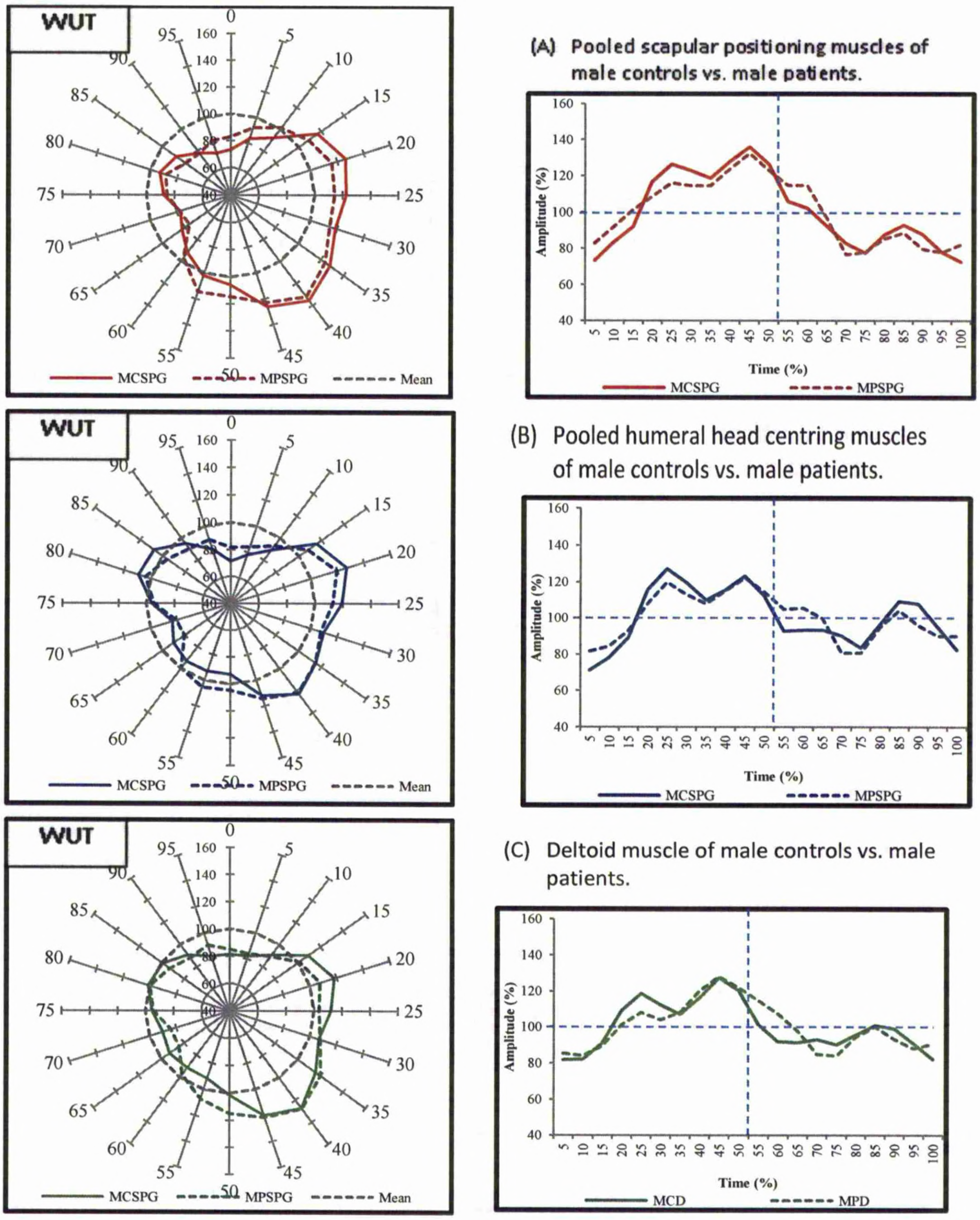


Figure 6 - 16: Activation pattern of shoulder muscle groups during waist-up task (WUT).

The scapular positioning, (LS, UT, LT, SA and RM), humeral head centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) groups in male controls (left) and male impingement patients (right).



%	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(A)	0.27	0.24	0.13	0.23	0.15	0.46	0.87	0.90	0.61	0.50	0.17	0.08	0.39	0.46	0.78	0.55	0.30	**0.04**	0.98	0.20
(B)	0.08	0.19	0.56	0.15	0.26	0.37	0.92	0.99	0.79	0.83	0.14	**0.04**	0.24	0.30	0.55	0.41	0.18	**0.01**	0.26	0.26
(C)	0.29	0.27	0.76	0.33	0.27	0.31	0.90	0.80	0.33	0.48	0.08	**0.02**	0.13	0.23	0.72	0.78	0.92	0.53	0.58	0.27

Figure 6 - 17: Comparing muscle groups between male controls (MC-) and patients (MP-) during waist-up task (WUT).

The statistical difference (p values) at every 5% interval of (A) Scapular Positioning, (B) Humeral head centring, and (C) Deltoid muscle. Bold values are statistically significant (p<0.05).

With the hand landing on the higher shelf, the activation of muscle groups declined almost in parallel with the SP and HHC groups showing a plateau activity during the contact. An additional interesting finding was the behaviour of the deltoid and HHC groups within the 60 -75% interval. The flat pattern of the deltoid in male controls suggested that the arm was not lowered as much as the case in female controls [Figure 6 – 14 and Figure 6 - 16], and rather maintained a relatively lower level on its way to approach the lower shelf. The third peak (in phase 2) was lower than the first two peaks (mid-point of 85% interval) with HHC group leading the movement followed by the deltoid and then the SP group.

In male patients, phase 1 started with higher level of muscle activity in the SP and HHC group compared to the controls, the deltoid showed a similar pattern in both patient and control groups. SP group showed steep increase in the activity with concomitant delayed and lower activity in HHC and deltoid groups. All achieved their first peak at mid-point of 25% interval similar to controls, however at a lower level. The second peak (mid-point of 45% interval) showed similar position and order of muscles [Figure 6 - 16 and Figure 6 - 15]. During higher shelf-contact, the pattern was similar to controls but at a higher level of activity and significantly different for HHC and deltoid groups ($p<0.05$, at 60% interval). During arm lowering, all groups showed steep decline to a lower level than that in controls. The last peak was a sharp decline in muscle activity to a lower level than that of controls with significant difference for SP and HHC groups ($p<0.05$, at 90% interval).

6.2.5 Muscle Activation Patterns for Individual Shoulder Muscles within Muscle Groups during Waist-Up Task

The results of activation patterns for muscle groups indicated greater differences in female groups (early, mid-, or late intervals of both phases) compared to limited differences in male groups (early and late intervals of phase 2). Further supportive details were obtained from comparisons of individual muscle activation patterns contributing to each muscle group between female [Figure 6 - 18 and Table 6 - 11] and male participants [Figure 6 - 19 and Table 6 - 12].

6.2.5.1 Activation Patterns of Individual Muscles in Female Participants

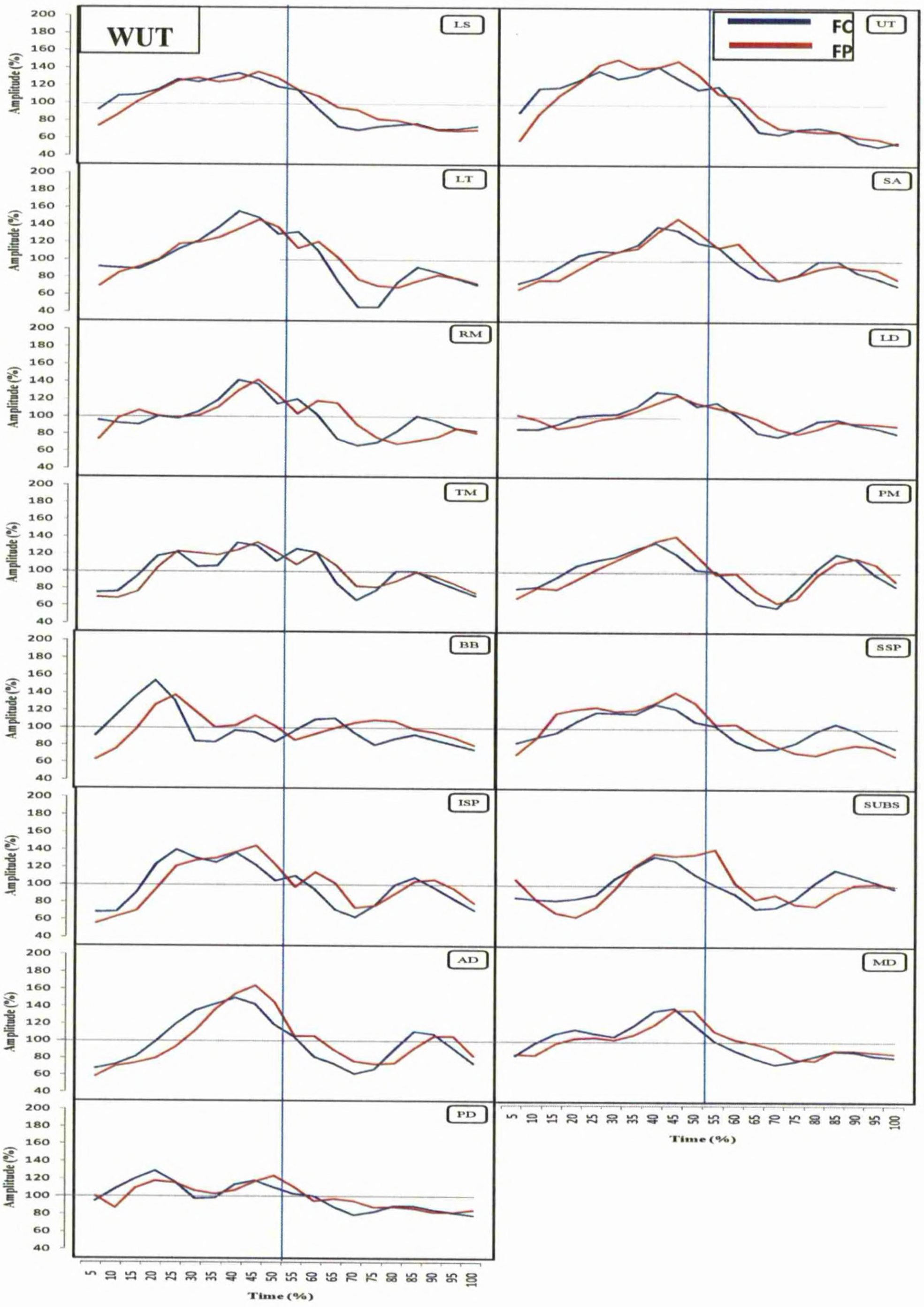


Figure 6 - 18: Comparison of averaged activation curves between female controls (FC, blue lines) and patients (FP, red lines) during waist-up task (WUT).

Table 6 - 11: Activation pattern differences in individual shoulder muscles within muscle groups as compared between female patients and controls during waist-up task.

Bold blue p-values indicate significant difference with lower contribution in patients, while bold red p-values indicate higher contribution in patients.

		Phase (1) Arm elevation										Phase (2) Arm lowering									
	Muscle	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**	**100%**
Scapular positioning	LS	0.05	**0.03**	0.48	0.78	0.69	0.93	0.90	0.66	0.90	0.12	0.60	**0.02**	**0.00**	**0.01**	0.24	0.40	0.73	0.69	0.90	0.76
	UT	**0.02**	**0.02**	0.69	0.73	0.60	0.31	0.39	0.90	0.14	0.09	0.60	0.20	**0.05**	0.69	0.79	0.69	1.00	0.48	0.40	0.90
	LT	**0.05**	0.66	0.63	0.93	0.63	0.76	0.10	**0.03**	0.43	0.48	0.12	0.69	0.16	**0.03**	0.12	0.38	0.09	1.00	0.93	0.73
	SA	0.48	0.63	0.06	**0.04**	0.40	0.97	0.69	0.93	0.31	0.32	0.73	**0.02**	0.08	0.65	0.90	0.16	0.43	0.42	**0.04**	0.36
	RM	0.09	0.88	0.28	0.84	0.93	0.79	0.43	0.40	0.79	0.54	0.17	0.47	**0.04**	0.11	0.62	0.21	**0.01**	0.17	0.93	0.98
Humeral head centring	LD	0.09	0.12	0.38	**0.05**	0.19	0.46	0.40	0.05	0.43	0.93	0.60	0.60	0.09	0.48	0.43	0.07	0.63	0.79	0.66	0.17
	TM	0.40	0.38	0.10	0.26	0.93	0.07	0.14	0.76	0.83	0.76	0.10	1.00	0.25	0.19	0.51	0.06	0.86	0.42	0.19	0.24
	PM	0.17	0.76	0.12	**0.02**	0.29	0.98	0.69	0.90	0.07	0.12	0.60	**0.05**	0.10	0.69	0.24	0.48	0.20	1.00	0.10	0.48
	BB	**0.03**	**0.00**	**0.01**	0.09	0.36	**0.01**	0.33	0.90	**0.05**	0.07	0.46	0.19	0.40	0.43	**0.03**	0.09	0.46	0.36	0.14	0.40
	SSP	0.12	0.40	0.10	0.15	0.31	0.73	0.86	0.90	0.05	**0.01**	0.83	**0.01**	0.08	0.86	0.07	**0.00**	**0.00**	**0.05**	0.24	0.31
	ISP	0.16	0.38	**0.03**	**0.01**	**0.05**	0.51	0.29	0.73	**0.01**	0.09	0.36	0.10	**0.04**	0.36	0.90	0.19	0.51	0.29	0.09	0.15
	SUBS	0.43	0.62	0.28	**0.05**	0.21	0.26	0.75	0.93	0.62	0.19	0.34	0.21	0.43	0.28	0.54	**0.02**	0.14	0.37	0.93	0.79
Deltoid	AD	0.17	0.93	0.97	0.22	**0.02**	**0.03**	0.19	0.86	**0.05**	**0.03**	0.79	**0.01**	0.17	0.19	0.63	**0.01**	**0.01**	0.54	0.17	0.20
	MD	0.66	0.12	0.17	0.17	0.43	0.63	0.37	0.11	0.57	0.08	0.24	0.10	**0.03**	0.07	0.79	0.27	0.90	0.76	0.83	0.57
	PD	0.66	0.27	0.40	0.29	0.73	0.43	0.66	0.86	0.86	0.06	0.36	0.48	0.16	**0.04**	0.40	0.93	0.73	0.76	0.66	0.29

In female patients, LS, UT, LT and BB showed significant decrease of activity at 5%-10% intervals, as the loaded hand was in contact with the lower shelf and the shoulder muscles were in preparation to initiate arm elevation. When the hand moved upwards (20%-25% intervals), significant decrease in activity of LD, PM, ISP, SUB, SA and AD was observed. Furthermore, significant decrease in muscle activity of patients was noted for BB, SSP, ISP and AD as the arm was approaching the end of phase 1 (45%-50% intervals).

In contrast to phase 1, all muscles of the SP group, PM, SSP and ISP of the HHC group and all deltoid components showed significant increased activity when the loaded hand attempted to leave the higher shelf and move downwards (60%-70% intervals). Further significant decrease in patients' muscle activity was evident for the RM, SSP, SUBS and AD at 80%-85% intervals when the arm was elevating and the elbow extending so that the hand could approach the start point. A substantial major decrease in activity appeared to a great extent in BB followed by ISP and AD in phase 1 and SSP in phase 2.

6.2.5.2 Patterns of Individual Muscle in Male Participants

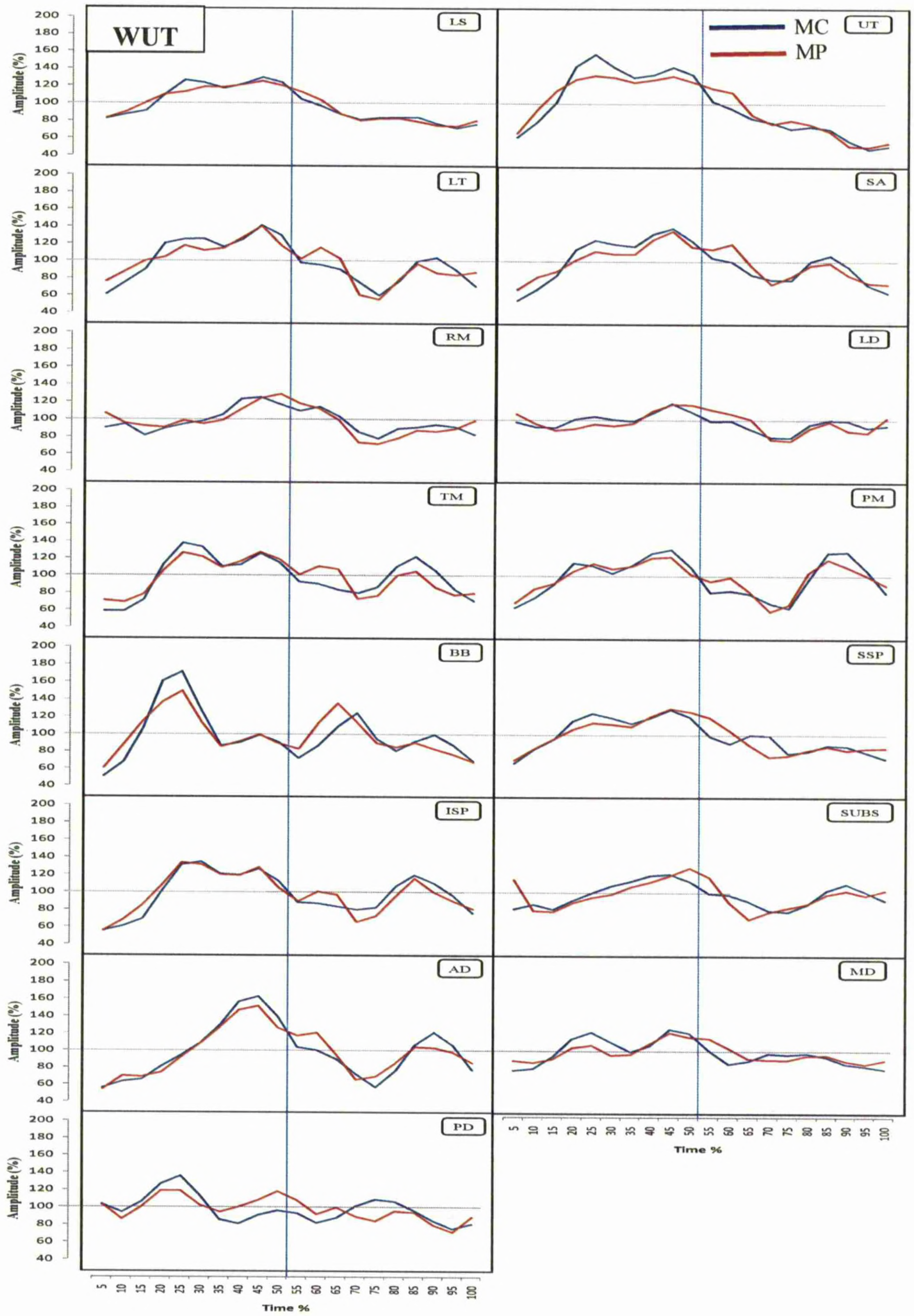


Figure 6 - 19: Comparison of averaged activation curves between male controls (MC, blue lines) and male patients (MP, red lines) during waist-up task (WUT).

Table 6 - 12: Activation pattern differences in individual shoulder muscles within muscle groups as compared between male patients and controls during waist-up task (WUT).

Bold blue p-values indicate significant difference with lower contribution in patients, while bold red - values indicate higher contribution in patients.

		Phase (1) WUT - Arm elevation										Phase (2) WUT Arm lowering									
Muscle		**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**	**100%**
Scapular positioning	LS	0.92	0.76	0.11	0.90	0.09	0.74	0.34	0.47	0.78	0.57	**0.05**	0.19	0.92	0.94	0.83	0.60	0.17	0.83	0.63	0.80
	UT	0.59	0.44	0.26	0.20	**0.04**	0.55	0.97	0.31	0.59	0.33	0.12	0.07	0.80	0.69	0.55	0.63	0.78	0.51	0.72	0.59
	LT	0.19	0.34	0.40	0.06	0.39	0.34	0.57	0.87	0.92	0.17	0.63	0.25	0.36	0.39	0.80	0.92	0.55	**0.01**	0.31	**0.05**
	SA	0.09	0.13	0.63	0.09	0.06	0.11	0.69	0.92	0.98	0.99	0.24	0.06	0.36	0.90	0.83	0.23	0.08	0.13	0.92	0.31
	RM	0.92	0.33	0.17	0.95	0.97	0.38	0.36	0.14	0.52	0.70	0.87	0.53	0.80	0.53	0.51	0.41	0.87	0.27	0.72	0.11
Humeral head centring	LD	0.67	0.83	0.47	0.07	0.08	0.29	0.83	0.44	0.74	0.33	0.29	0.14	0.07	0.92	0.67	0.33	0.76	0.08	0.13	0.41
	TM	0.23	0.17	0.12	0.37	0.17	0.25	0.80	0.63	0.67	0.67	0.53	**0.04**	**0.03**	0.34	0.30	0.07	**0.02**	0.05	0.72	0.19
	PM	0.29	0.12	0.76	0.11	0.72	0.97	0.99	0.49	0.18	0.29	0.09	0.09	0.94	0.63	0.65	0.55	0.12	0.07	0.65	0.30
	BB	0.36	0.10	0.47	0.12	0.20	0.61	0.90	0.99	0.80	0.78	0.27	0.07	**0.04**	0.33	0.31	0.74	0.61	**0.02**	0.21	0.80
	SSP	0.51	0.51	0.90	0.17	0.31	0.63	0.83	0.37	0.94	0.90	0.06	0.11	0.65	0.59	0.79	0.90	0.92	0.42	0.94	0.76
	ISP	0.57	0.55	**0.03**	0.47	0.83	0.53	0.80	0.76	0.51	0.49	0.94	0.13	0.36	0.19	0.42	0.13	0.76	0.26	0.90	0.65
	SUBS	**0.02**	0.80	0.90	0.97	0.87	0.29	0.39	0.38	0.82	0.33	**0.05**	0.61	0.05	0.61	0.78	0.87	0.36	0.08	0.78	0.15
Deltoid	AD	0.69	0.41	0.80	0.30	0.99	0.87	0.90	0.69	0.55	0.25	0.13	0.07	0.63	0.90	0.53	0.37	0.97	0.08	0.47	0.55
	MD	0.51	0.28	0.80	0.19	0.13	0.07	0.87	0.61	0.80	0.46	0.08	**0.02**	0.24	0.18	0.53	0.97	0.51	0.39	0.74	0.09
	PD	0.63	0.59	0.67	0.44	0.13	0.52	0.17	**0.01**	**0.02**	**0.01**	0.11	0.12	0.25	0.25	**0.02**	0.59	0.97	0.80	0.85	0.08

The activation pattern of individual muscles revealed only limited alterations in male patients during WUT when compared to controls. PD was the only muscle that showed a pattern of significant increase in activity within the last three intervals of phase 1. During phase 2 few significant changes in muscle activity were observed in early and late intervals which were in line with significant changes in male muscle groups described earlier in section 6.2.4.2 [Figure 6 - 17]. LS, TM, BB, SUBS and MD showed increased activity at 55%-65% intervals, while the activity of LT, TM and BB decreased significantly at 85%-90% interval.

6.3 Eye-Down Task

The EDT tested the dynamic activity of the shoulder during a loaded forward arm elevation and lowering to move 1 kg of weight between a shelf at the eye level and a lower shelf located 25 cm below [Figure 6 - 20]. The arm was elevated to reach 70° to 100° of combined flexion and abduction of the shoulder (about the first half of the range of the painful arc in patients with SIS). The arm tested in patients was the affected arm and either the dominant or non-dominant arm of the healthy subjects. The task was repeated for 60 seconds and 10 mid-cycles were used for the analysis.

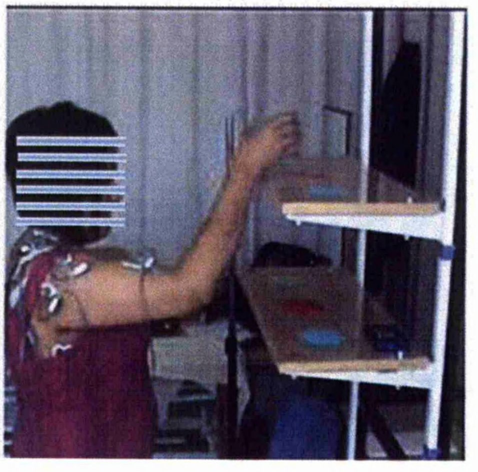


Figure 6 - 20: Eye-down task

It involves moving a load of 1 kg between a shelf placed at the eye level and a lower shelf placed 25cm. below. A full cycle composed of two phases: Phase (1) included contact lower shelf and moving toward higher shelf; Phase (2) included contact higher shelf and moving back to the start point on the lower shelf.

6.3.1 Cycle Duration

The average duration of 10 cycles was divided into the duration of shelf-contact and off-shelf time during arm elevation (phase1) and arm lowering (phase2) of the EDT. The percentage of shelf-contact and off-shelf in each phase was calculated from the averaged cycle duration and presented for comparisons in Table 6 - 13.

Table 6 - 13: Comparing the time Percentage of the phase components (shelf-contact and off-shelf) within female (subacromial impingement syndrome (SIS) patients, n=13; controls, n=13) and male (SIS patients, n=16; controls, n=20) subjects during eye-down task (EDT). Bold p values are statistically significant (p<0.05).

Group	EDT	Phase (1) Arm elevation					Phase (2) Arm lowering				
		SIS Patients		Controls		p value	SIS Patients		Controls		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female	Shelf-Contact	12.0	3.0	6.0	3.4	**0.00**	12.9	3.2	7.0	3.7	**0.00**
	Off-Shelf	38.6	3.1	44.4	3.6	**0.00**	36.6	3.6	42.6	3.9	**0.00**
Male	Shelf-Contact	9.8	4.6	11.5	6.2	0.45	10.6	4.5	11.1	5.4	0.88
	Off-Shelf	40.4	4.9	39.2	5.2	0.63	39.1	4.4	38.2	6.4	0.69

In the female groups, the mean time (%) of shelf-contact was significantly higher in both phases but significantly lower in off-shelf in both phases in female patients when compared to control subjects. Although the comparisons in male groups showed no significant difference, the opposite trend to that reported in female groups was evident in both phases of EDT.

6.3.2 Mean Amplitude

The normalized mean amplitude of phase 1 and phase 2 was used to perform intra-group and inter-group comparisons during the EDT [Table 6 – 14 and Table 6 -15]. In female patients and controls, intra-group comparisons of phase 1 and phase 2 mean amplitude %, revealed a matched highly significant difference for all muscles (p<0.05) except for SUBS in patients [Table 6 - 9]. In male groups, a matched significant difference was documented for all muscles except for the BB in both male patients and controls; and SUBS in patients [Table 6 - 9]. Inter-groups differences for each phase were only significantly different between female groups for SSP in phase 1 and ISP in phase 2 [Table 6 - 10].

6.3.3 Muscle Activation Pattern

EMG recordings during dynamic standardised movements of arm elevation and lowering task in healthy subjects and patients allowed the identification of patterns of muscle activity for the different muscle groups. In female controls [Figure 6 – 21], the SP group was the leading muscle group with higher contribution as the arm elevation progressed that was followed immediately by the HHC group.

Table 6 - 14: Normalized mean amplitude (%) comparison between phase 1 and phase 2 in female (subacromial impingement syndrome (SIS) patients=13, Controls=13) and male (SIS patients = 16, Controls =20) subjects during the eye-down task. Bold *p* values are statistically significant (p<0.05).

Muscle Groups	Muscle	SIS Patients					Controls				
		Phase 1		Phase 2		*p* value	Phase 1		Phase 2		*p* value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular positioning	LS	112.7	7.8	88.0	6.2	**0.00**	115.5	6.6	83.8	6.7	**0.00**
	UT	117.5	8.0	83.3	7.4	**0.00**	117.1	6.5	82.1	6.6	**0.00**
	LT	114.2	5.0	85.9	5.5	**0.00**	118.3	9.2	81.3	9.1	**0.00**
	SA	107.6	5.6	93.3	5.4	**0.00**	110.4	5.2	89.5	5.6	**0.00**
	RM*	112.7	7.3	88.2	6.5	**0.00**	113.0	9.9	86.8	9.9	**0.00**
Humeral Head Centring	LD	105.9	5.1	95.1	5.0	**0.01**	107.7	3.0	92.1	3.1	**0.00**
	TM	108.0	4.4	93.3	4.4	**0.00**	109.7	5.1	89.3	5.9	**0.00**
	PM	108.7	5.7	92.1	5.1	**0.00**	107.9	8.5	92.6	8.1	**0.01**
	BB	104.4	7.4	96.6	6.8	**0.04**	106.2	6.6	93.6	6.2	**0.01**
	SSP	113.5	8.8	87.3	8.1	**0.00**	110.7	8.8	89.7	8.5	**0.00**
	ISP	111.1	3.5	90.2	3.5	**0.00**	114.6	7.8	85.3	7.2	**0.00**
	SUBS*	99.9	19.3	90.4	15.6	0.10	108.6	9.5	91.4	9.9	**0.02**
Deltoid	AD	114.5	7.7	86.6	6.9	**0.00**	118.4	8.3	82.1	7.9	**0.00**
	MD	110.6	11.4	90.9	10.9	**0.02**	118.4	8.8	81.9	8.4	**0.00**
	PD	110.6	6.7	90.9	5.7	**0.00**	115.2	10.2	84.1	9.0	**0.00**
Male Group											
Scapular positioning	LS	111.1	5.7	89.5	6.4	**0.00**	111.7	8.2	88.9	7.8	**0.00**
	UT	113.8	8.5	86.5	9.0	**0.00**	113.0	6.7	87.6	6.6	**0.00**
	LT	114.8	6.5	85.3	6.7	**0.00**	113.6	7.6	87.8	6.3	**0.00**
	SA	108.4	5.1	91.5	4.5	**0.00**	108.5	11.6	92.9	10.4	**0.00**
	RM	112.5	9.7	89.3	9.6	**0.00**	107.2	14.5	93.2	15.2	**0.00**
Humeral Head Centring	LD	105.2	4.5	95.1	5.0	**0.00**	106.8	7.1	94.0	5.6	**0.00**
	TM	107.1	5.4	93.2	5.9	**0.00**	106.7	7.9	94.6	6.6	**0.00**
	PM	107.2	7.9	92.9	8.1	**0.01**	106.7	8.0	94.0	7.0	**0.00**
	BB	100.6	6.4	99.4	7.3	0.61	103.6	11.8	97.3	9.7	0.22
	SSP	109.8	5.3	90.4	5.7	**0.00**	111.3	10.0	89.2	6.9	**0.00**
	ISP	108.1	8.5	92.8	9.9	**0.01**	108.8	8.7	92.4	7.3	**0.00**
	SUBS	104.6	9.9	95.6	9.9	0.08	109.8	8.9	91.2	7.8	**0.00**
Deltoid	AD	112.2	5.2	88.4	4.5	**0.00**	114.2	11.3	87.3	9.1	**0.00**
	MD	110.6	6.4	89.7	6.0	**0.00**	112.1	13.8	89.6	10.9	**0.00**
	PD	108.8	5.2	91.5	5.2	**0.00**	108.7	9.1	91.8	8.8	**0.00**

Table 6 - 15: Normalized mean amplitude (%) comparison within female (subacromial impingement syndrome (SIS) patients=16, Controls=13) and male (SIS patients = 18, Controls =19) subjects during phases 1 and 2 of the eye-down task. Bold p values are statistically significant ($p<0.05$).

Muscle Groups	Muscle	Phase 1 Mean Amplitude %					Phase 2 Mean Amplitude %				
		SIS Patients		Control		p value	SIS Patients		Control		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Female Group											
Scapular positioning	LS	112.7	7.8	115.5	6.6	0.29	88.0	6.2	83.8	6.7	0.13
	UT	117.5	8.0	117.1	6.5	0.70	83.3	7.4	82.1	6.6	0.59
	LT	114.2	5.0	118.3	9.2	0.37	85.9	5.5	81.3	9.1	0.25
	SA	107.6	5.6	110.4	5.2	0.14	93.3	5.4	89.5	5.6	**0.04**
	RM	112.7	7.3	113.0	9.9	1.00	88.2	6.5	86.8	9.9	0.74
Humeral Head Centring	LD	105.9	5.1	107.7	3.0	0.17	95.1	5.0	92.1	3.1	**0.04**
	TM	108.0	4.4	109.7	5.1	0.59	93.3	4.4	89.3	5.9	0.23
	PM	108.7	5.7	107.9	8.5	0.43	92.1	5.1	92.6	8.1	0.46
	BB	104.4	7.4	106.2	6.6	0.49	96.6	6.8	93.6	6.2	0.32
	SSP	113.5	8.8	110.7	8.8	0.40	87.3	8.1	89.7	8.5	0.40
	ISP	111.1	3.5	114.6	7.8	0.21	90.2	3.5	85.3	7.2	**0.04**
	SUBS	99.9	19.3	108.6	9.5	0.38	90.4	15.6	91.4	9.9	0.91
Deltoid	AD	114.5	7.7	118.4	8.3	0.23	86.6	6.9	82.1	7.9	0.16
	MD	110.6	11.4	118.4	8.8	**0.04**	90.9	10.9	81.9	8.4	**0.02**
	PD	110.6	6.7	115.2	10.2	0.17	90.9	5.7	84.1	9.0	**0.05**
Male Group											
Scapular positioning	LS	111.1	5.7	111.7	8.2	0.43	89.5	6.4	88.9	7.8	0.61
	UT	113.8	8.5	113.0	6.7	0.95	86.5	9.0	87.6	6.6	0.77
	LT	114.8	6.5	113.6	7.6	0.52	85.3	6.7	87.8	6.3	0.31
	SA	108.4	5.1	108.5	11.6	0.87	91.5	4.5	92.9	10.4	0.73
	RM	112.5	9.7	107.2	14.5	0.82	89.3	9.6	93.2	15.2	0.84
Humeral Head Centring	LD	105.2	4.5	106.8	7.1	0.66	95.1	5.0	94.0	5.6	0.55
	TM	107.1	5.4	106.7	7.9	0.77	93.2	5.9	94.6	6.6	0.43
	PM	107.2	7.9	106.7	8.0	0.70	92.9	8.1	94.0	7.0	0.77
	BB	100.6	6.4	103.6	11.8	0.46	99.4	7.3	97.3	9.7	0.36
	SSP	109.8	5.3	111.3	10.0	0.61	90.4	5.7	89.2	6.9	0.28
	ISP	108.1	8.5	108.8	8.7	0.95	92.8	9.9	92.4	7.3	0.92
	SUBS	104.6	9.9	109.8	8.9	0.19	95.6	9.9	91.2	7.8	0.20
Deltoid	AD	112.2	5.2	114.2	11.3	0.24	88.4	4.5	87.3	9.1	0.24
	MD	110.6	6.4	112.1	13.8	0.73	89.7	6.0	89.6	10.9	0.82
	PD	108.8	5.2	108.7	9.1	0.80	91.5	5.2	91.8	8.8	0.85

Towards the middle of phase 1 and as the SP and HHC groups showed a balanced range of activation, the deltoid group activation coincided with further arm elevation towards the higher shelf at the eye level. As soon as the arm was lowered with the hand resting at the higher shelf deltoid activity, it showed a steady fall while the SP and HHC showed a gradual decrease in activity during higher shelf-contact period; then sloped down sharply and almost parallel to the deltoid as the arm was lowered in phase 2. The observed slight increase in activity of the three groups at the second half of phase 2 coincided with reaching the lower shelf and the return to the starting position. It is important to observe that towards the end of the cycle, both the HHC and deltoid muscles reduced their activity while the activity in SP muscles increased to prepare the scapula for the next cycle. In female patients [Figure 6 - 21], the leading group was also the SP muscle group.

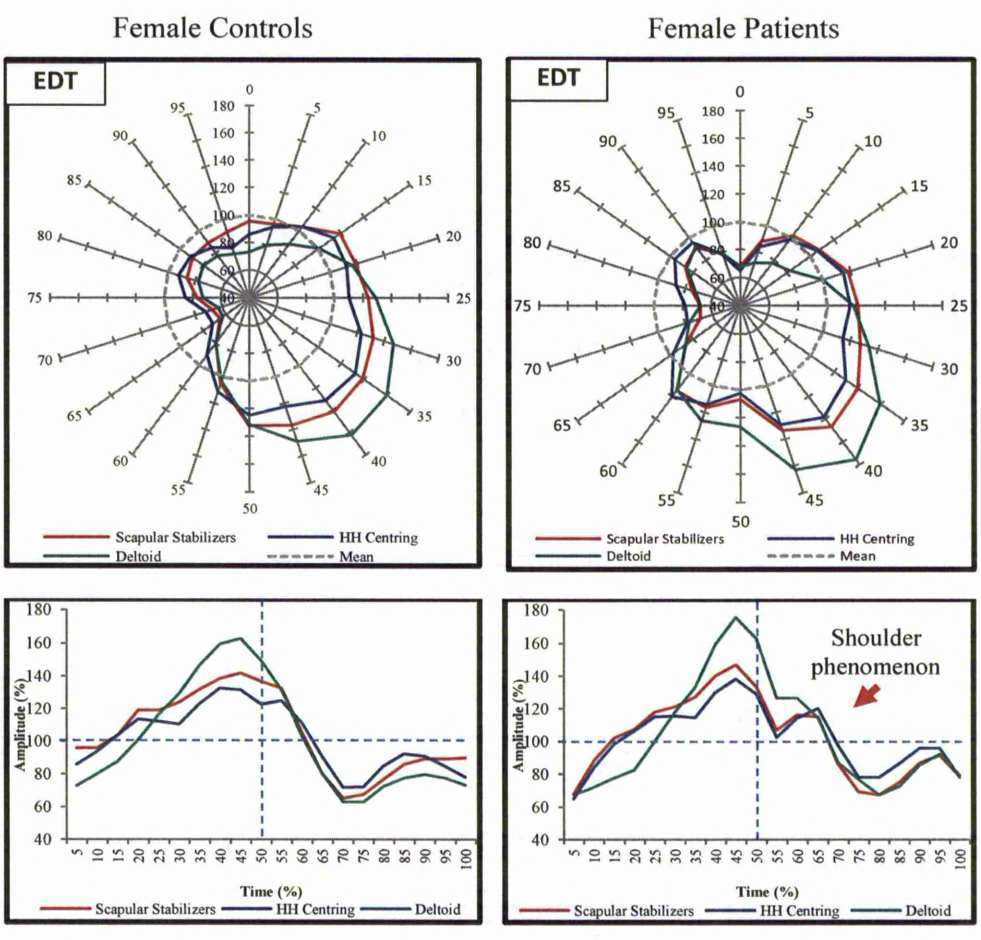
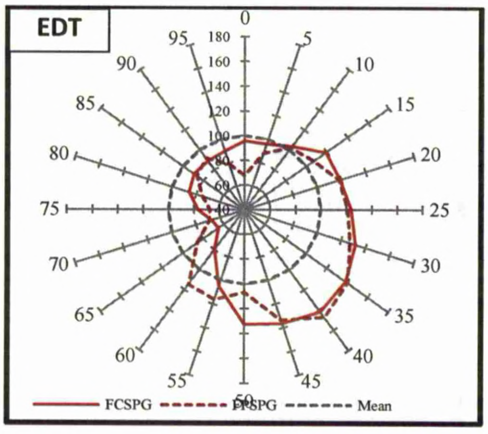
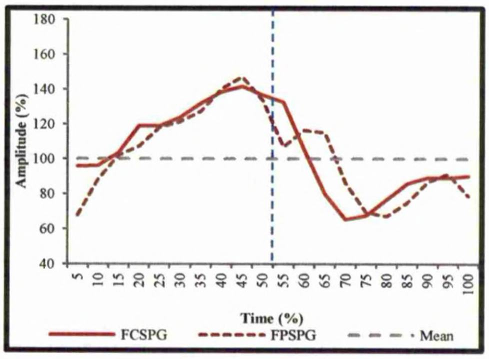


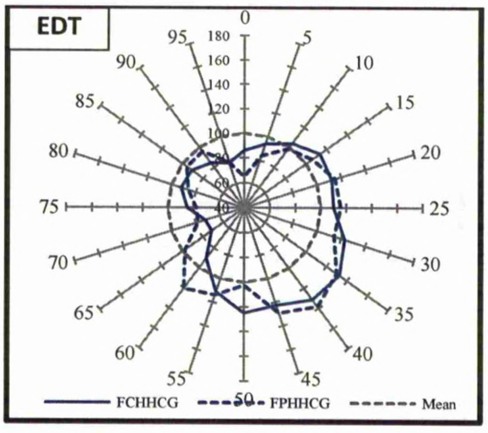
Figure 6 - 21: Activation patterns of shoulder muscle groups during eye-down task (EDT)

The scapular positioning (LS, UT, LT, SA and RM), humeral head (HH) centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) groups in female controls (left) and female impingement patients (right).

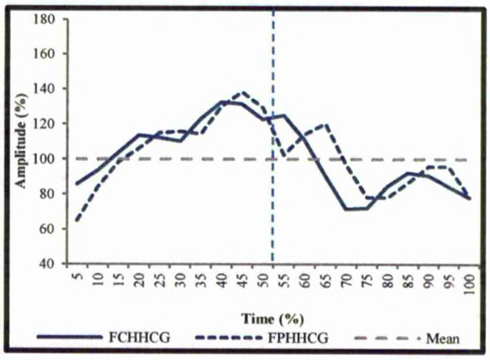


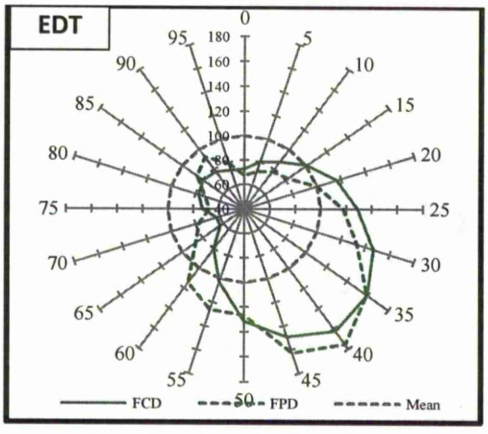
(A) Pooled scapular positioning muscles of female controls vs. female patients



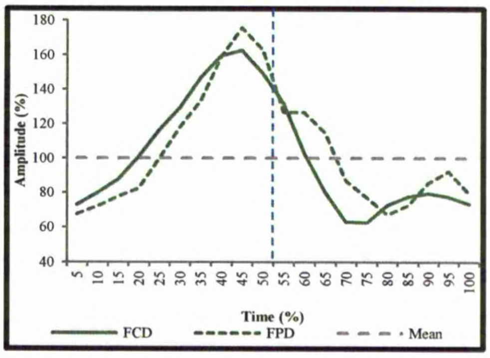


(B) Pooled humeral head centring muscles of female controls vs. female patients.





(C) Deltoid muscle of female controls vs. female patients.



%	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(A)	**0.01**	0.37	0.66	0.28	0.56	0.86	0.29	0.63	0.14	0.86	**0.03**	0.46	**0.00**	**0.01**	0.96	0.13	**0.05**	0.74	0.84	**0.04**
(B)	**0.02**	0.40	0.52	0.13	0.34	0.14	0.37	0.59	0.32	0.21	0.09	0.72	**0.01**	**0.01**	0.59	0.16	0.14	0.84	**0.04**	0.94
(C)	0.49	0.40	0.22	0.12	0.32	0.49	0.21	0.66	0.46	0.25	0.40	**0.03**	**0.01**	**0.02**	0.13	0.59	0.46	0.17	**0.00**	0.17

Figure 6 - 22: Comparing muscle groups between female controls (FC-) and patients (FP-) during eye-down task (EDT)

The statistical difference (*p* values) at every 5% interval of (A) Scapular Positioning (SPG), (B) Humeral head centring (HHCG), and (C) Deltoid (D) muscle groups. Bold values are statistically significant ($p<0.05$).

It was significantly observed that SP and HHC groups started their activity from relatively lower levels as compared to controls (p=0.01 and p=0.02, respectively, Figure 6- 3) Their activity increased steeply and parallel to each other but with delay to reach a level of stability. There was also delay in the firing of the deltoid group though not statistically significant. The deltoid group contributed highly in patients than controls to raise the hand to eye level. It is also important to notice the 'shoulder-like appearance' of the three curves due to sharp and brief significant increase in activity (p value ranged from 0.02 to <0.01 at 65% and 70% intervals (early phase2) [Figure 6 - 22]. This 'shoulder phenomenon' was concomitant with early movement of the arm downwards in phase 2. Finally, towards the last two intervals of the cycle, the patients showed significant increased activity in the deltoid (p<0.01) and HHC (p<0.05). The SP muscle activity in patients showed a higher significant decline than controls by the end of the cycle (p<0.05) [Figure 6- 3].

Male Controls Male Patients

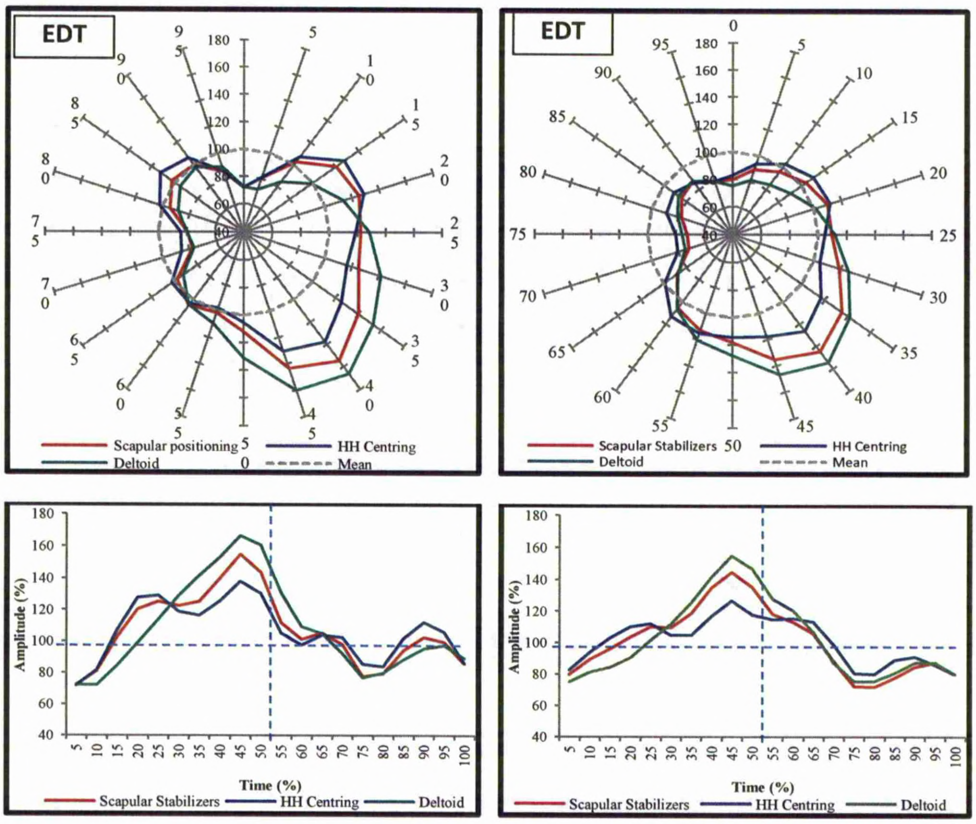
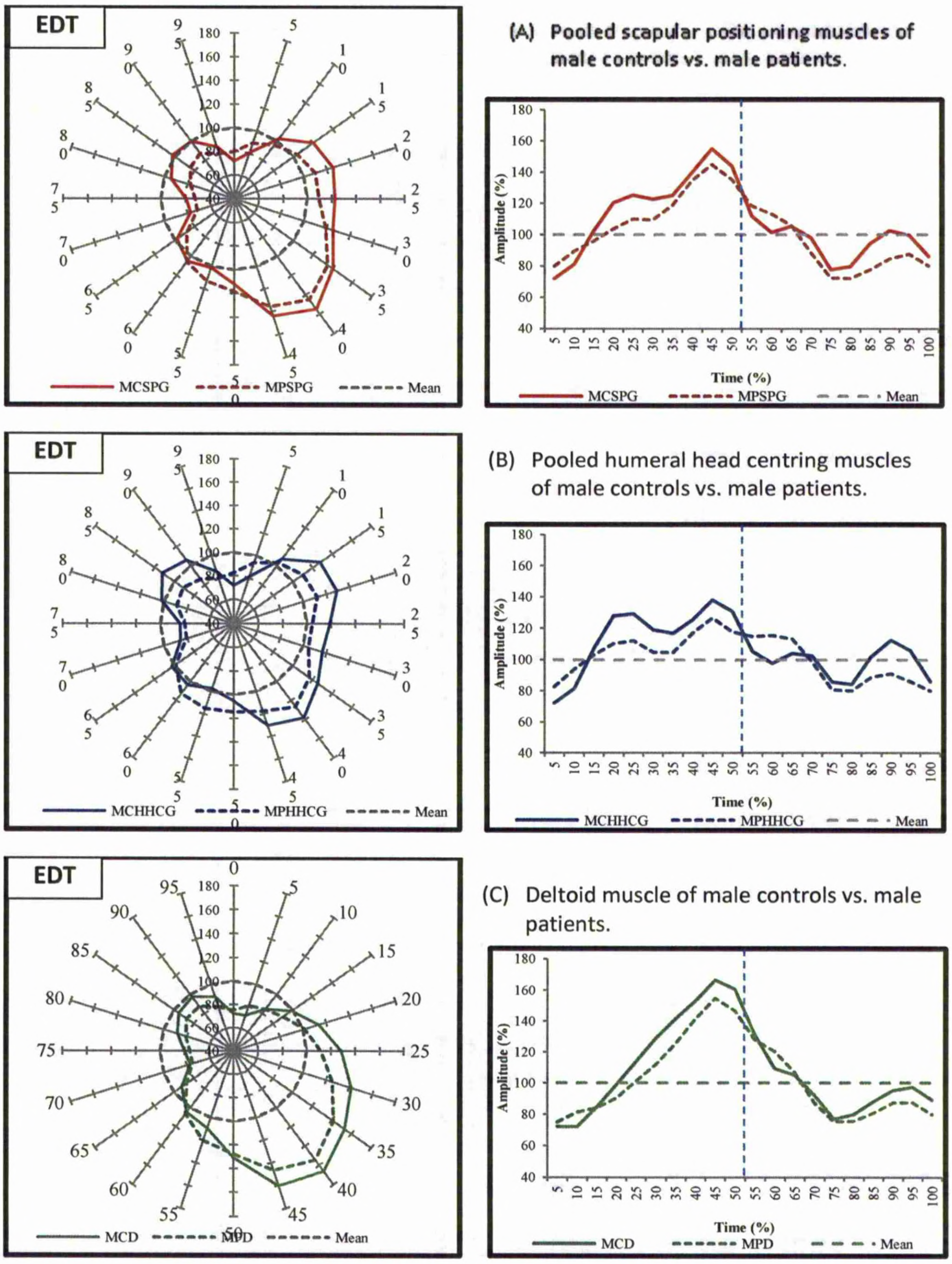


Figure 6 - 23: Activation patterns of shoulder muscle groups during eye-down task (EDT)

The scapular positioning, (LS, UT, LT, SA and RM), humeral head (HH) centring (LD, TM, PM, BB, SSP, ISP and SUBS) and deltoid (AD, MD and PD) groups in male controls (left) and male SIS patients (right) during EDT.



%	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
(A)	0.24	**0.05**	0.19	**0.00**	**0.01**	**0.01**	0.38	0.19	0.23	0.47	0.40	0.09	0.99	0.26	0.50	0.40	**0.00**	**0.00**	**0.00**	0.13
(B)	0.17	0.12	0.74	**0.00**	**0.01**	**0.01**	**0.03**	0.22	**0.05**	**0.03**	0.16	**0.02**	0.27	0.69	0.50	0.43	**0.00**	**0.00**	**0.00**	0.07
(C)	0.70	0.10	0.80	0.06	**0.01**	**0.00**	**0.01**	0.15	0.12	0.14	0.78	0.27	0.86	0.38	0.99	0.58	0.19	0.12	**0.01**	**0.03**

Figure 6 - 24: Comparing muscle groups between male controls (MC-) and patients (MP-) during eye-down task (EDT)

The statistical difference (*p* values) at every 5% interval of (A) Scapular Positioning (SPG), (B) Humeral head centring (HHCG), and (C) Deltoid (D) muscle groups during EDT. Bold values are statistically significant ($p<0.05$).

In male controls [Figure 6 - 23], as the upward movement arm was initiated, the SP and HHC groups showed a simultaneous sharp rise in activity during early phase 1 followed by increased HHC activity towards the mid-phase when it was over taken by the increased activity of SP group. Interestingly, the deltoid group showed a rapid increase across other 2 groups as they change their activity about mid-phase1. The activity of the 3 muscle groups was almost proportional towards the end of phase 1 and early phase two. This relationship changed as soon as the arm attempted to move downwards, when the HHC group took the leading activity, followed by SP and the deltoid groups. The last pattern was maintained but with proportional increase in activity as the hand approached the start point on the lower shelf. Finally, all the muscle groups declined to the same level by the end of the cycle.

As for the male patients [Figure 6 - 23 and Figure 6 - 24], although both SP and HHC groups started simultaneously with a steep rise in their activity the HHC showed a higher contribution. Both groups did not reach the level of activity around mid-phase of arm elevation when compared with controls ($p \leq 0.01$, at 20-30% intervals). The deltoid group significantly showed a gradual increase in activity, a delay in firing, and achieved a lower level of activity than the deltoid in controls ($p \leq 0.01$, at 25-35%). As the arm was further elevated in the second half of phase 1, the 3 muscle groups showed an almost similar pattern to controls until early phase 2. The 'shoulder phenomenon' was obvious, however less prominent than in female patients with the only significant difference seen for the HHC group in patients when compared with controls. Finally it was documented that there was an increased activity of the 3 groups when the hand was approaching the start point that were significantly lower in activity than the controls (p value ranged from <0.05 to <0.01, at last 3 intervals).

6.3.4 Muscle Activation Patterns of Individual Shoulder Muscles within the Muscle Groups

Based on muscle group activation patterns and comparisons in the previous section, it was clear that significant differences were confirmed at early, mid-, or late intervals of each phase with some variation between genders. Further supportive details were obtained from comparisons of the individual muscles within the muscle groups between female [Figure 6 - 25 and Table 6 - 16], and male participants [Figure 6 - 26 and Table 6 - 17].

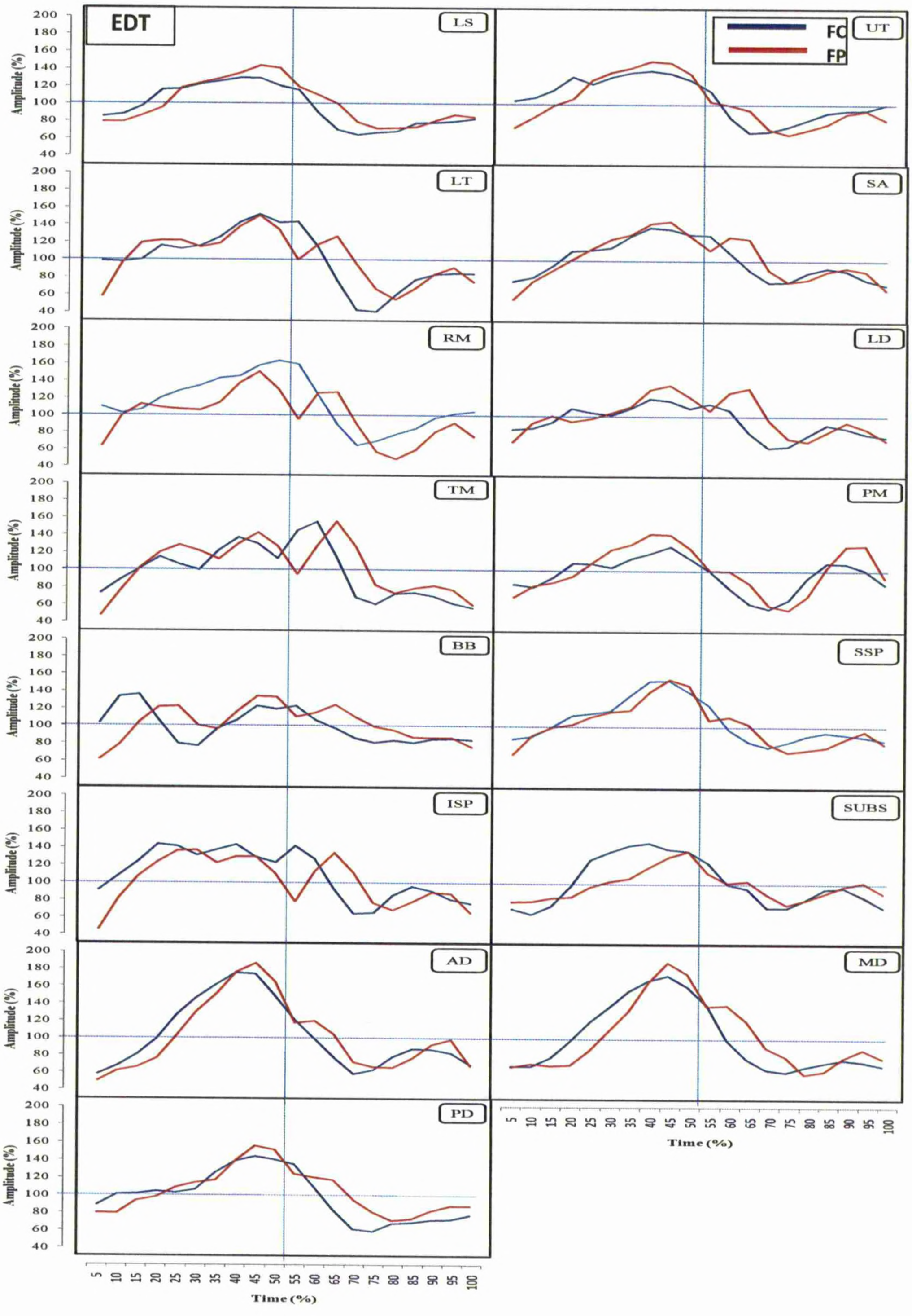


Figure 6 - 25: Comparing the activation pattern of 15 shoulder muscles between female controls (FC, blue line) and patients (FP, red line) during phase1 and phase2 of the eye-down task (EDT).

Table 6 - 16: Differences between female patients and controls in the averaged activation curves of 15 shoulder muscles during eye-down task.

Bold blue p-values indicated significant difference with lower contribution in patients, while bold red p-values indicated higher contribution in patients

Cycle		Phase (1) Arm elevation										Phase (2) Arm lowering									
Muscle		**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**	**100%**
Scapular positioning	LS	0.43	0.32	0.21	**0.00**	0.82	0.82	0.74	0.82	0.17	0.25	0.78	**0.04**	**0.01**	0.06	0.51	0.59	0.21	0.91	0.38	0.83
	UT	**0.01**	0.13	0.16	**0.00**	0.49	0.59	0.70	0.11	0.17	0.34	0.14	0.14	**0.01**	0.59	0.30	0.14	0.06	0.45	0.96	0.21
	LT	**0.00**	0.98	0.07	0.63	0.40	0.90	0.74	0.74	0.90	0.74	**0.00**	0.91	**0.01**	**0.00**	**0.04**	0.21	0.45	0.66	0.28	0.33
	SA	**0.01**	0.56	0.40	0.66	0.63	0.43	0.90	0.59	0.46	0.90	0.27	0.21	**0.03**	0.25	0.83	0.30	0.96	0.62	0.16	0.23
	RM	**0.00**	0.95	0.27	0.62	0.76	0.39	0.39	0.95	0.71	0.27	**0.00**	0.84	0.06	**0.04**	0.79	0.24	0.19	0.26	0.95	0.21
Humeral Head Centring	LD	**0.00**	0.86	0.82	**0.00**	0.27	0.78	0.63	0.78	0.17	0.37	0.13	0.51	**0.00**	**0.00**	0.59	0.14	0.11	0.70	0.79	0.13
	TM	**0.01**	0.49	0.94	0.98	**0.02**	**0.05**	0.17	0.40	0.56	0.34	**0.01**	0.21	0.06	**0.00**	**0.04**	0.83	0.62	0.19	0.05	0.66
	PM	0.13	0.98	0.06	**0.01**	0.52	0.14	0.27	**0.04**	0.25	0.78	0.49	0.09	**0.03**	0.96	**0.03**	**0.01**	0.30	0.33	0.17	0.96
	BB	**0.00**	0.00	0.08	0.32	**0.00**	**0.04**	0.59	0.66	0.94	0.40	0.32	0.62	0.05	**0.04**	0.14	0.79	0.79	0.62	0.96	0.36
	SSP	**0.04**	0.98	0.78	0.19	0.46	0.98	0.17	0.40	0.40	0.32	0.21	0.11	**0.02**	0.62	0.11	**0.03**	**0.02**	0.25	0.48	0.25
	ISP	**0.00**	0.13	0.32	**0.02**	0.40	0.59	0.21	0.52	0.90	0.74	**0.00**	0.45	**0.02**	**0.00**	0.59	**0.05**	**0.01**	0.66	0.21	0.51
	SUBS	0.79	0.19	0.19	0.90	**0.03**	**0.01**	**0.01**	0.08	0.47	0.79	0.24	0.67	0.67	0.18	0.83	0.72	0.48	0.78	0.23	0.23
Deltoid	AD	0.29	0.40	**0.03**	0.07	**0.04**	0.21	0.21	0.90	0.40	0.34	0.34	0.12	**0.02**	0.17	0.94	**0.05**	0.23	0.27	**0.02**	0.78
	MD	0.70	0.63	0.32	0.09	**0.04**	0.06	0.12	0.52	0.37	0.25	0.70	**0.01**	**0.00**	0.10	0.09	0.41	0.48	0.48	**0.04**	0.16
	PD	0.29	0.05	0.34	0.49	0.59	0.37	0.66	0.86	0.59	0.52	0.34	0.48	**0.01**	**0.01**	0.03	0.45	0.55	0.19	0.05	0.17

Figure 6 - 25 represents the averaged activity curves of individual muscles in female participants. Corresponding to averaged activation curves [Figure 6 -25], Table 6 -16 compares the activation of muscles as per defined intervals for each phase. The results revealed significant differences during the course of the eye-down cycle. In preparation for arm elevation (early phase 1) all SP muscles except LS, and HHC muscles except for PM and SUBS, showed similar pattern with less contribution in the female patients. There was no difference in deltoid activation. As the arm progressed in elevation, at about 70-80° of combined flexion and abduction at GHJ (about mid-phase), the LS and UT within SP group, and all HHC muscles except SSP, showed significant decline in contribution in female patients. The AD and MD also reflected similar patterns at mid-phase. During the higher shelf-contact (early phase 2), LT, RM, TM and ISP had higher contribution in the female patients. As soon as the loaded hand left the higher shelf and the arm attempted to move downwards (just before mid-phase), a substantial and significant contribution was evident for all muscle except SUBS in female patients. This interesting pattern coincided with ‘shoulder phenomenon’. Further significant changes were obvious in the second half of phase two when female patients additionally demonstrated less contribution in PM,SSP,ISP, AD and MD.

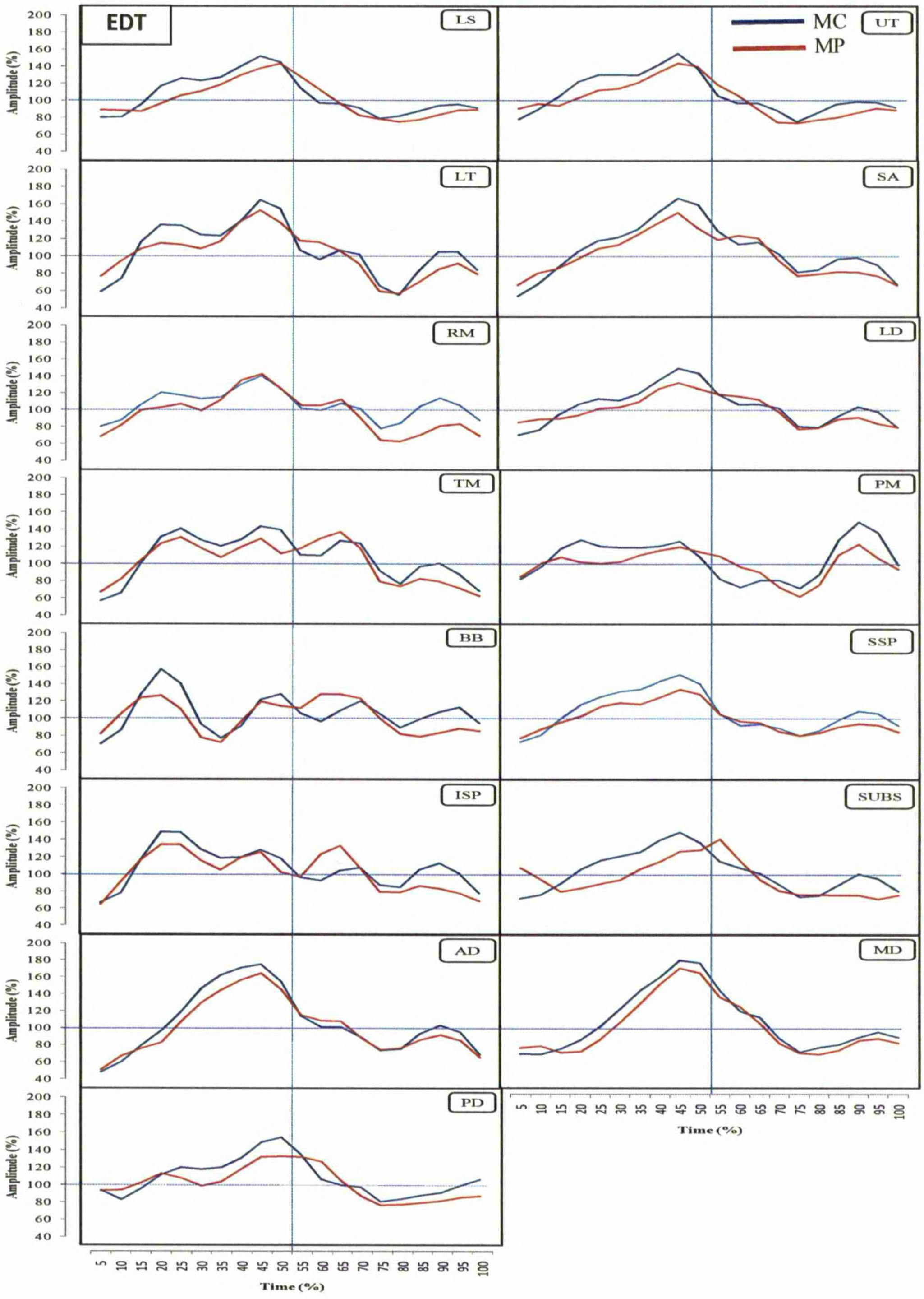


Figure 6 - 26: Comparing the activation pattern of 15 shoulder muscles between male controls (MC, blue line) and patients (MP, red line) during eye-down task (EDT).

Figure 6 - 26 compared the individual averaged curves of muscles in male participants and revealed the significant differences at the pre-defined intervals

during the course of the eye-down cycle. A higher percentage of significant changes resulted from comparing the activation pattern between male patients and controls that were confined at and around mid-phase of arm elevation and in the second half of phase 2 towards the end of arm lowering. All muscles participated in the significant lower contribution of male patients on at least two occasions. The higher contribution of muscles in male patients was associated with 'shoulder phenomenon' (60% interval) and was still manifested but to a lesser degree than that in female patients. Only four muscles including LS, PM, BB, and ISP showed a significantly higher contribution at about 60% interval.

Table 6 - 17: Differences between male patients and controls in the averaged activation curves of 15 shoulder muscles during eye-down task.

Bold blue p-values indicated significant difference with lower contribution in patients, while bold red p-values indicated higher contribution in patients.

Cycle		Phase (1) Arm elevation										Phase (2) Arm lowering									
	Muscle	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**	**100%**
Scapular positioning	LS	0.46	0.10	0.38	**0.03**	**0.03**	0.06	0.22	0.21	0.23	0.83	0.10	**0.02**	0.88	0.36	0.83	0.26	**0.03**	**0.03**	0.14	0.50
	UT	0.20	0.39	0.11	**0.02**	0.12	**0.04**	0.36	0.43	0.67	0.38	**0.05**	0.27	0.41	0.09	0.85	0.20	**0.01**	**0.02**	0.34	0.90
	LT	0.13	0.03	0.54	0.05	**0.02**	0.14	0.76	0.93	0.30	0.16	0.34	0.16	0.69	0.38	1.00	0.98	**0.03**	**0.00**	**0.04**	0.43
	SA	0.09	0.02	0.95	0.17	0.09	**0.03**	0.38	0.18	0.12	**0.02**	0.43	0.41	0.76	0.43	0.98	0.85	**0.01**	**0.04**	0.08	0.67
	RM	0.39	0.69	0.30	**0.04**	0.15	0.45	0.52	1.00	0.90	0.74	0.93	0.33	0.88	0.58	0.60	0.45	**0.03**	**0.01**	**0.03**	**0.02**
Humeral Head Centring	LD	0.05	0.09	0.52	**0.02**	0.07	0.13	0.09	**0.03**	**0.00**	**0.02**	0.69	0.15	0.63	0.58	0.93	0.93	0.50	**0.02**	**0.00**	0.88
	TM	0.26	0.14	0.65	0.60	0.63	0.88	0.27	0.50	0.15	**0.00**	0.71	0.17	0.33	0.69	0.46	0.38	**0.02**	**0.01**	**0.01**	0.14
	PM	0.71	0.30	0.31	**0.00**	**0.01**	0.06	0.78	0.83	0.60	0.38	**0.02**	**0.01**	0.26	0.45	0.34	0.39	0.11	0.09	**0.01**	0.67
	BB	0.43	0.09	0.88	0.17	0.14	0.34	0.78	0.56	0.98	0.21	0.50	**0.04**	0.15	0.38	0.34	0.54	0.08	**0.02**	**0.02**	0.60
	SSP	0.52	0.26	0.41	0.06	0.34	0.19	0.07	**0.04**	**0.04**	0.17	0.93	0.48	0.98	0.65	0.60	0.74	0.18	**0.02**	**0.04**	0.31
	ISP	0.78	0.30	0.60	0.33	0.13	0.17	0.17	0.93	0.67	**0.04**	0.85	**0.04**	0.06	0.76	0.48	0.20	**0.01**	**0.00**	**0.00**	0.12
	SUBS	0.18	0.54	0.30	0.07	**0.04**	**0.02**	0.12	0.19	0.15	0.37	0.29	0.46	0.33	0.14	0.96	0.99	0.10	**0.00**	**0.01**	0.52
Deltoid	AD	0.90	0.23	0.74	**0.02**	0.14	**0.02**	**0.04**	0.26	0.71	0.48	0.98	0.54	0.46	0.88	0.90	0.71	0.19	0.09	0.18	0.39
	MD	0.60	0.23	0.54	**0.03**	**0.01**	0.09	0.06	0.45	0.13	0.18	0.67	0.50	0.69	0.38	0.81	0.52	0.50	0.46	**0.04**	0.27
	PD	0.98	0.30	0.27	0.90	0.15	**0.01**	0.06	0.27	0.16	0.09	0.58	0.06	0.21	0.36	0.76	0.41	0.29	0.25	0.06	**0.03**

6.3.5 Qualitative Assessment of Muscle Activation Pattern

It is important to provide a qualitative interpretation of muscle activation during this task, which requires arm elevation to a challenging height in patients with SIS; thus an additional description of muscle activation pattern is reported. The mean amplitude % for every muscle at each interval of the time domain was sorted from maximum to minimum values and then ranked to 'high, moderate or low activity' for the first five high values, second five values and last lower five values, respectively [Figure 6 – 27]. Table 6-6 below describes the individual muscle activation pattern of female controls during both phases of EDT, based on the relative activity of muscles in [Figure 6 – 27].

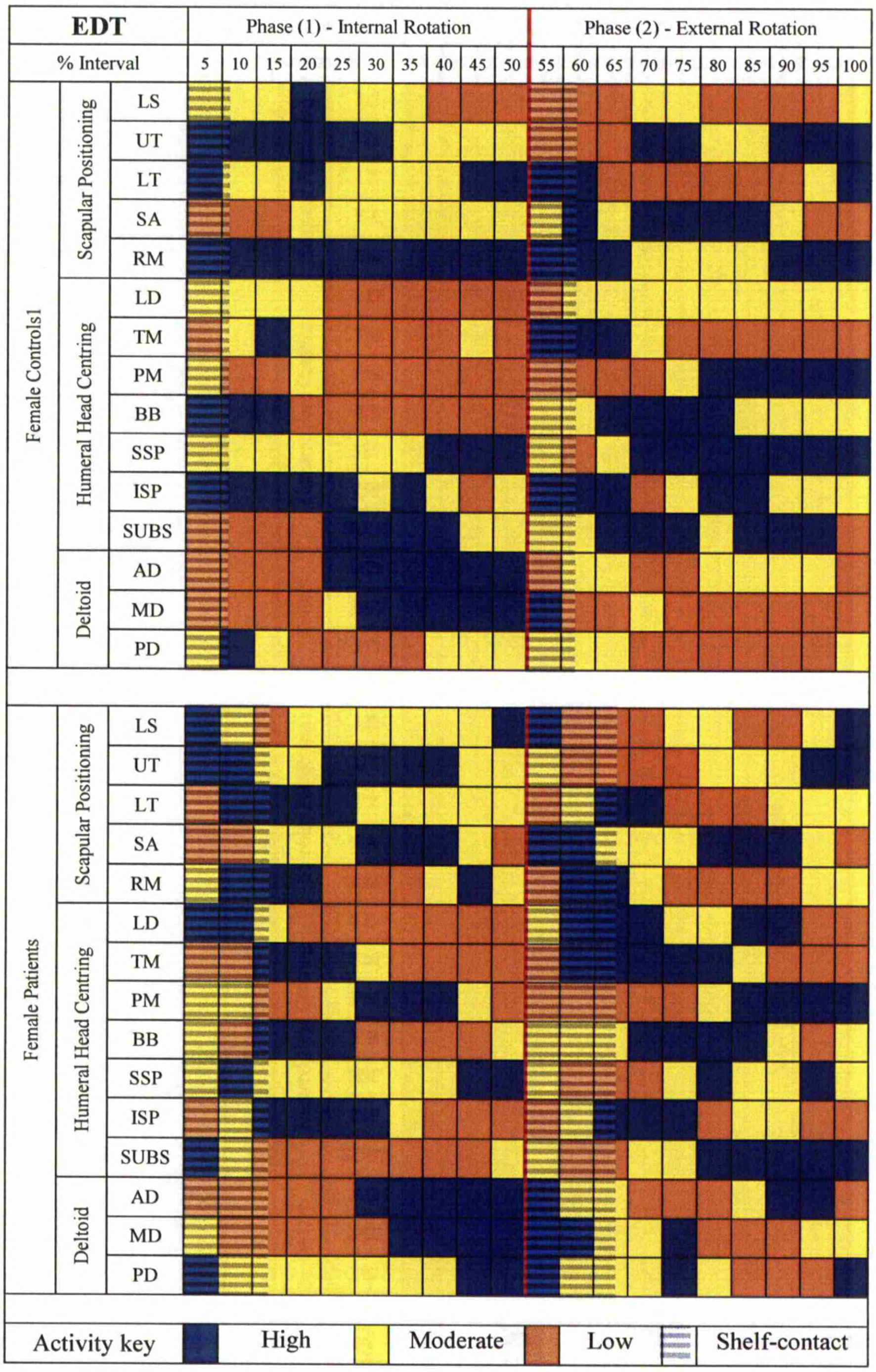


Figure 6 - 27 Qualitative assessment of muscle activation patterns in female groups during eye-down task (EDT)

The relatively high activity included the highest 5 values, the relatively low activity included the lowest 5 values, and the relatively moderate activity included the remaining 5 values of mean amplitude % at every 5% interval of the time domain (for shelf-contact duration see Table 6 - 13).

Table 6 - 18: Individual muscle activation pattern of female controls based on the qualitative assessment during eye-down task.

	Muscles	Phase 1	Phase 2	Remarks
Scapular Positioning	LS	Early moderate activity then mostly low activity in the second half.	Mostly low activity all through	Moderately active during arm elevation
	UT	Early high activity till mid-phase then moderate activity to the end	Low and high in first half then moderate and high activity in second half	High to moderate activity with arm elevation and lowering
	LT	High activity at extremes and moderate in between	High activity at extremes and low in between	Moderately active during arm elevation
	SA	Early low activity then predominant moderate activity to the end.	Mostly high activity the dropped to low very late in phase	Moderately activity with arm elevation and high with lowering
	RM	High activity all through	Early high activity then moderate at mid-range and again high to end	It appeared as the most active muscle particularly with arm elevation
Humeral head Centring	LD	Moderate at the first half then low activity in the second half	Moderate activity through the whole phase	Moderate activity at first half of elevation and all through arm lowering.
	TM	Low-high-low fluctuation in first half then maintained low activity in second half	Early high activity then gradual decline to low	Fluctuating at lower shelf-contact and early elevation; and high activity at higher shelf-contact and early lowering
	PM	Mostly low activity through the whole phase	Low activity in first half then high in second half	Most active with arm lowering as approaching the start point
	BB	Mostly high activity in first half then low activity to end	Moderate to high activity in first half then mostly moderate to end	High activity at lower shelf-contact and initial elevation, but mostly active with arm lowering (elbow flexion)
	SSP	Moderate to high activity through the whole phase	Mostly high activity through the phase	Moderate activity with elevation, advanced to high as approaching the higher shelf and during arm lowering
	ISP	High activity in first half and mostly moderate in the second half	Mostly high activity in first half and moderate in the second half	High activity in initial half-range of elevation and fluctuating moderate to low through arm lowering
	SUBS	Low activity initially, advanced to high about mid-phase and changed to moderate by the end	Moderate to high activity in first half and mostly high in second half	High activity with arm elevation about the higher shelf, initial lowering and as hand approaching the lower shelf
Deltoid	AD	Low activity in first half then abrupt high activity from before mid-phase to the end	Mostly moderate activity	Low activity with initial arm elevation. High activity with increased elevation until landing on higher shelf. Persisting moderate activity with arm lowering
	MD	Similar pattern following AD	Predominant low contribution	Similar to AD, but less activity during arm lowering
	PD	Low activity at mid-range but increase at extremes	Low activity at mid-range but increase at extremes	Increased activity associated with brief shoulder extension when the hand just pulled away from the shelf in both phases

6.3.5.1 Relative Muscle Activity Alterations in Scapular Positioning Group of Female Patients

The relatively high activity was reduced in patients by 2% in phase 1 and 6% in phase 2, the relatively moderate activity was reduced in phase 1 by 2% and increased in phase2 by 5%, and the relatively low activity increased in phase 1 by 4% and phase 2 by 1% [Figure 6 - 28A]. The significant altered relative activity was documented for RM as its activity was reduced in both phases. The UT activity was also reduced particularly in phase 2, while the LT showed increased activity with early arm elevation and decreased activity by the end of elevation. The SA showed increased activity at mid-range of elevation but only minor inter-change in activity in the lowering phase [Figure 6 - 27].

6.3.5.2 Relative Muscle Activity Alterations in Humeral Head Centring Group of Female Patients

The relatively high activity increased by 2% in phase 1 and 1% in phase 2, the relatively moderate activity decreased by 1% in phase 1 and 4% in phase 2, and the relatively low activity increased by 5% only in phase 2 [Figure 6 - 28B]. The muscle strategy was clearly altered and muscles such as LD, TM, and PM showed abrupt and brief increments in activity. The activity was reduced for SSP (phase 2), ISP (both phases) and SUBS (particularly phase 1) [Figure 6 – 27].

6.3.5.3 Relative Muscle Activity Alterations in Deltoid of Female Patients

The relatively high activity increased by 13% only in phase 2, the relatively moderate activity increased by 3% only in phase 1, and the relatively low activity decreased by 3% in phase 1 and 13% in phase 2 [Figure 6 - 28]. No major changes were observed in AD and MD (phase 1) but PD showed relative increased activity. In phase 2, all muscles showed abrupt and brief increase in activity that was not seen in female controls [Figure 6 - 27].

6.3.5.4 Relative Muscle Activity Alterations in Scapular Positioning Muscles of Male Patients

The relatively high activity was increased in male patients by 1% in phase 1 and reduced by 3% in phase 2, the relatively moderate activity was increased in phase 1 by 2% and decreased in phase2 by 3%, and the relatively low activity increased in phase 1 by 3% and phase 2 by 6% [Figure 6 – 30A].

The high-altered relative activity was observed for RM as its activity was reduced in both phases. The UT activity was also reduced particularly in phase 2. The SA and LT probably attempted compensatory action.

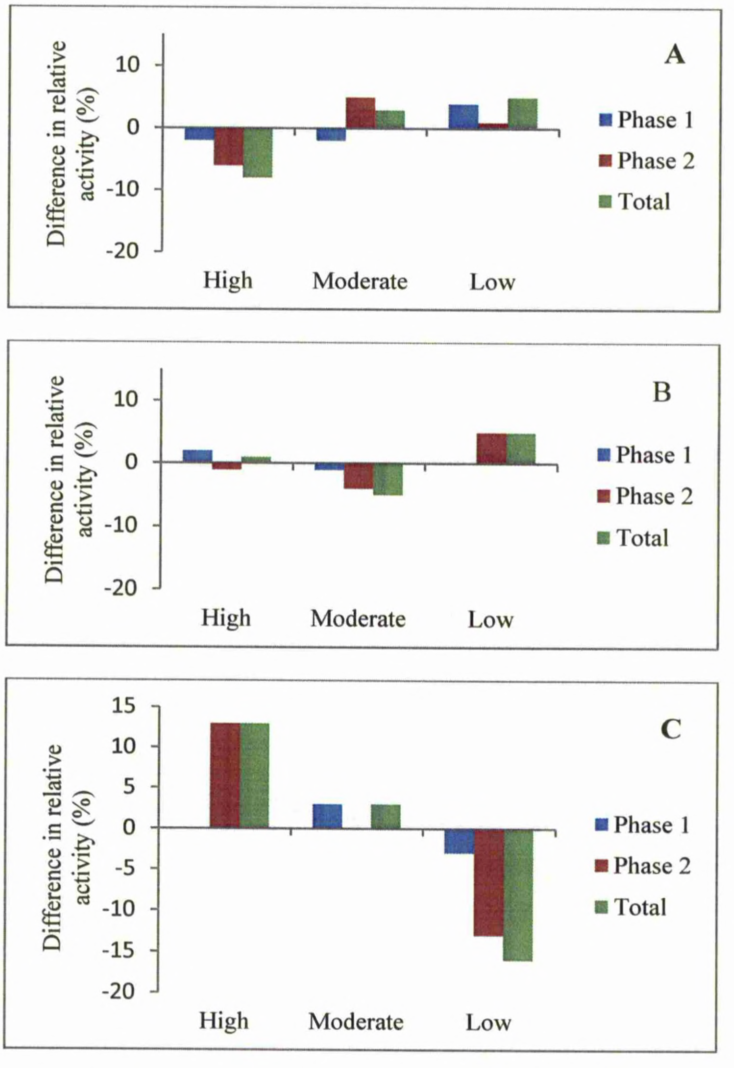


Figure 6 - 28: The percentage difference of the relative activity in female groups during eye-down task.

(A) Scapular positioning muscle group, (B) Humeral head centring group and (C) Deltoid

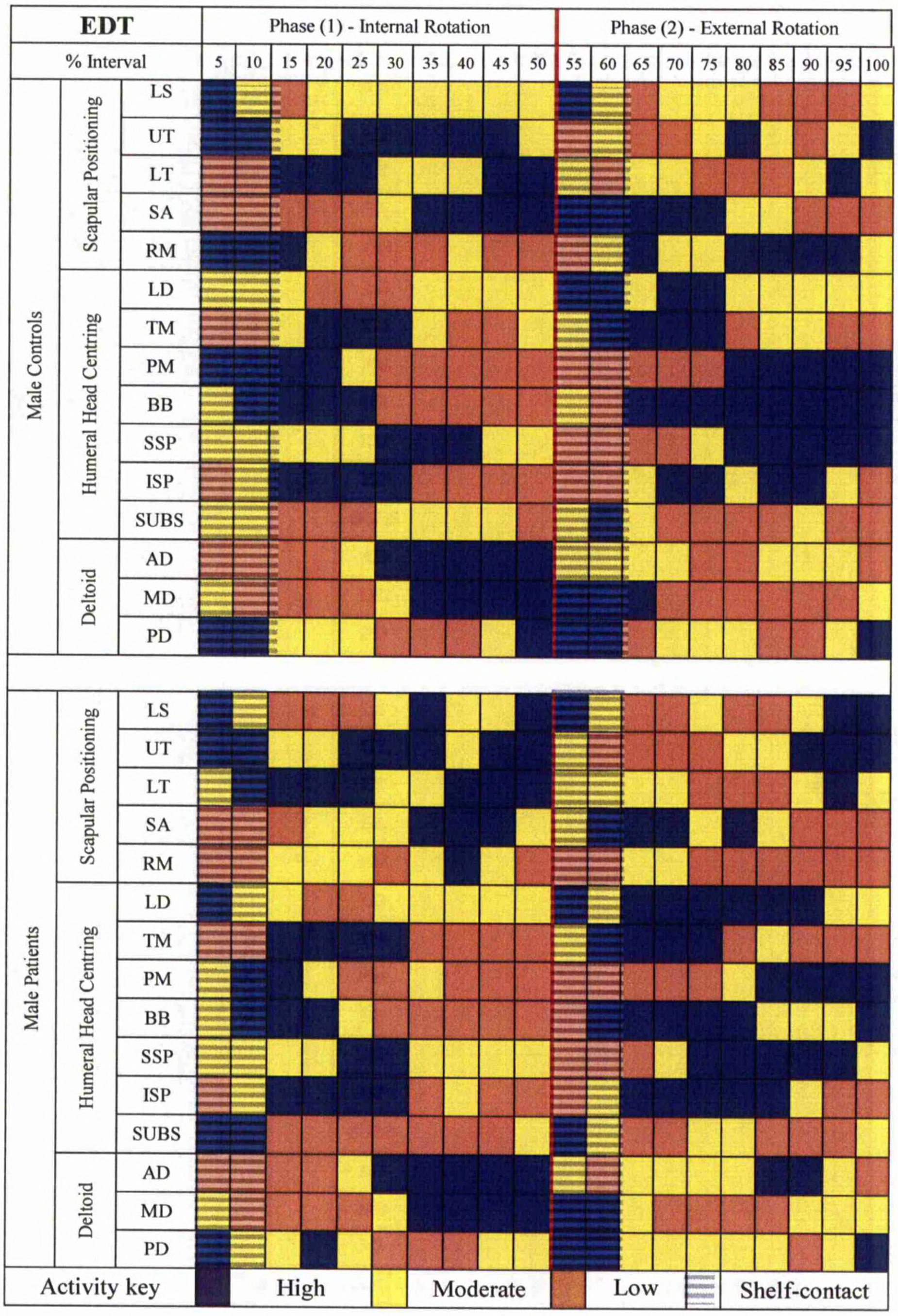


Figure 6 - 29: Qualitative assessment of muscle activation patterns in male groups during eye-down task (EDT).

The relatively high activity included the highest 5 values, the relatively low activity included the lowest 5 values, and the relatively moderate activity included the remaining 5 values of mean amplitude % at every 5% interval of the time domain (for shelf-contact duration see Table 6 - 13).

Table 6 - 19: Individual muscle activation pattern of male controls based on the qualitative assessment.

	Muscles	Phase 1	Phase 2	Remarks
Scapular Positioning	LS	Just started high activity then mostly moderate all through	Just started high activity with mid-range moderate activity	Moderately active during arm elevation and early arm lowering
	UT	Mostly high and few moderate activity to the end	Fluctuating (low-high) all through	High activity with arm elevation and fluctuating with arm lowering
	LT	Started low activity but mostly high in first half and moderate in second half	Fluctuating (low-moderate)	High activity with early arm elevation and approaching the higher shelf and moderate in between.
	SA	Low activity in first half then advanced to higher activity in second half	Almost reversed mirror image to phase 1	High activity when arm elevated about 70-90° as approached and left the higher shelf
	RM	Mostly high activity in first half then dropped to low all through	Mostly moderate in first half and high in second half	High activity with early arm elevation and second half of arm lowering
Humeral head Centring	LD	Mostly moderate activity accept mid-range low activity	Mostly high activity in first half and moderate in second half	Moderate activity with early arm elevation and when approaching the higher shelf. High to moderate activity with arm lowering.
	TM	Early low activity, advanced to mid-range high activity, then fluctuated (mod.-low)	Mostly high activity in first half and fluctuated in second half (low – moderate)	High activity at mid-range of arm elevation and first half of arm lowering
	PM	Mostly high activity in first half then low to end	A reversed mirror image to phase 1	High activity in early elevation and late lowering
	BB	Mostly high activity in first half, then low	Mostly high activity all through	High activity with early elevation and the whole range of lowering (elbow flexion)
	SSP	Moderate to high activity through the whole phase	Mostly low activity in first half and high activity in second half	Moderate to high activity with arm elevation. Low in early lowering but again high activity in second half of lowering
	ISP	Mostly high activity in first half	Fluctuating (low-high) all through	Interesting high activity with arm elevation and moderate to high during arm lowering
	SUBS	Started moderate activity but dropped , then raised to moderate again	Mostly low activity	Moderate activity at late arm elevation but mostly low with arm lowering (switch with ISP)
Deltoid	AD	Low activity in first half then increased to high activity in second half	Mostly moderate activity in first and second halves	Low activity with initial arm elevation. High activity with increased elevation. Moderate activity with early and late arm lowering
	MD	Almost similar to AD with slight delay	Early high activity the predominant low activity	Almost similar to AD with arm elevation but more active during early arm lowering
	PD	Early high activity, declined to moderate in first half. Mostly low in second half but advanced to high	Early high activity, fluctuated (low – moderate and end with brief high activity	Increased activity associated with brief shoulder extension when the hand just pulled away from the shelf in both phases. Further moderate activity in both phases should be considered in discussion

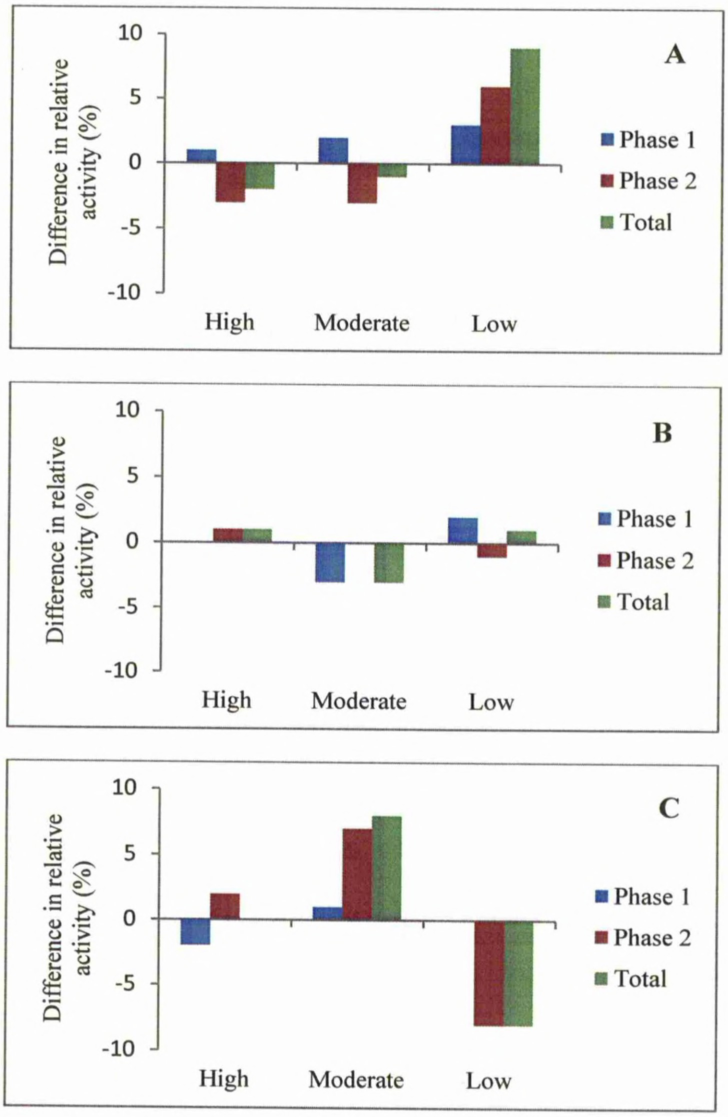


Figure 6 - 30: The percentage difference of the relative activity in male groups during eye-down task. (A) Scapular positioning muscle group, (B) Humeral head centring group and (C) Deltoid

6.3.5.5 Relative Muscle Activity Alterations in Humeral Head Centring muscles of Male Patients.

The relatively high activity was increased by 1% in phase 2 only, the moderate activity decreased by 3% in phase 1 and no change observed in phase 2, while the relatively low activity increased by 2% and reduced by 1% in phase 2 [Figure 6 - 30B]. In HHC muscles, the significant noted changes in phase 1 was seen for SUBS when the arm was elevated , while with arm lowering the LD and BB showed alterations. SUBS showed early increase in activity followed by reduced activity in the second half of phase 1. LD showed marked increase in activity with arm lowering, while the BB revealed reduced activity in the second half of arm lowering SSP. These particular findings appeared similar to that in the controls but a timing issue was observed as its sequences occupied one interval earlier than that in controls [Figure 6 - 11].

6.3.5.6 Relative Muscle Activity Alterations in Deltoid of Male Patients

The relatively high activity was reduced by 2% in phase 1 and increased by 2% in phase 2, the relatively moderate activity increased by 1% in phase 1 and 7% in phase 2, and the relatively low activity decreased by 8% in phase 2 only [Figure 6 - 30C]. Regarding the deltoid components, AD showed no change in phase 1 but the activity was increased in phase 2, whereas MD and PD showed no significant changes [Figure 6 - 11].

7 CHAPTER SEVEN: ELECTROMYOGRAPHY RESULTS – MUSCLE FATIGUE

Electromyography (EMG) is a standardised technique for measuring the fatigability of skeletal muscle. The quantification of EMG parameters can provide early detection of the fatiguing process in advance of any clinical sign of muscle fatigue. The commonly used EMG variable for assessing fatigue is the median frequency (MdF) of the power spectrum.

The fatigue protocol aimed to measure and compare the fatigability of 15 shoulder muscles in SIS patients and controls during a submaximal voluntary contraction (25% MVC) as previously described in the methods chapter (Chapter 3, section 3.7) during four distinct movements of the shoulder: forward flexion, abduction, external and internal rotation.

Fast Fourier transformation (FFT) was performed for power spectrum analysis using a predefined programme in the MyoResearch software. For fatigue measurements, MdF was calculated over 50 seconds at 1-s intervals and normalized to the initial MdF. Finally rates of change of MdF (slope) were quantified using linear regression (LINEST function in the Microsoft Excel 2007) and used as the muscle fatigue index (slope %/min). Results are shown as mean value and standard deviation (SD), or range, as appropriate.

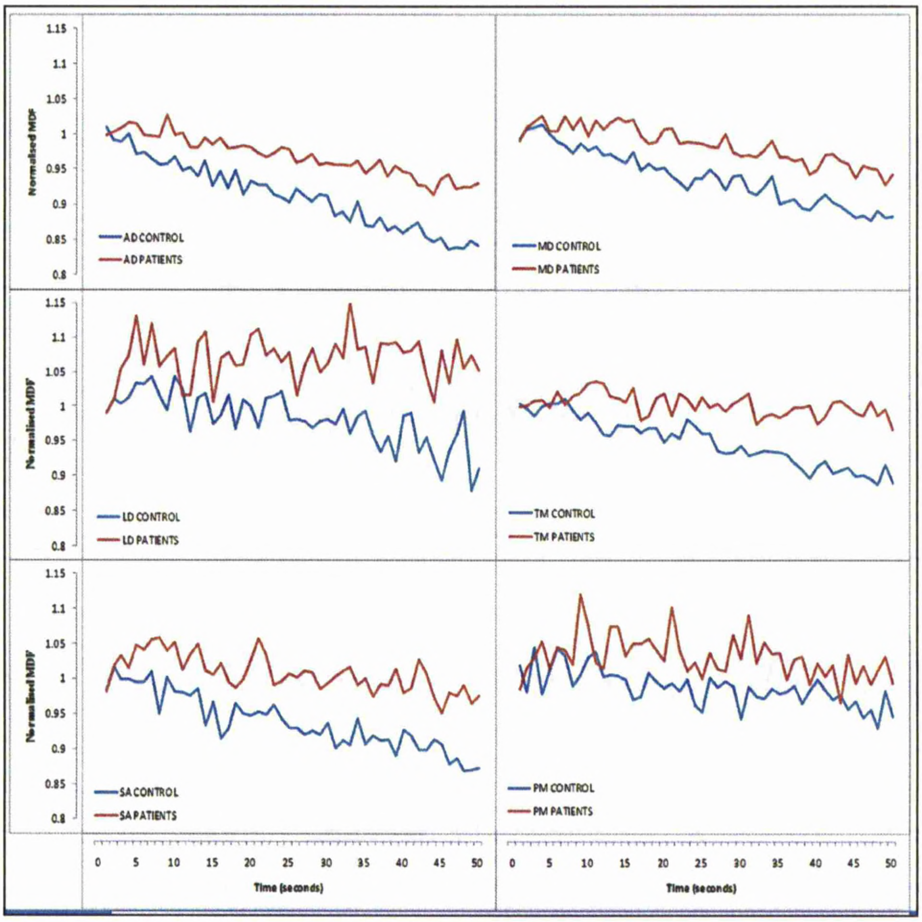


Figure 7 - 1: The fatigue slope (%/minute) during 50 seconds of isometric flexion at 25% maximum voluntary contraction (MVC) in SIS patients (red) and controls (blue).

7.1 Muscle Fatigue in Female Participants

There was a general trend for less muscle fatigue in patients compared to controls. During flexion, patients showed lower fatigue than controls in the majority of muscles except UT, BB and SUBS, which showed higher fatigability in patients. A statistically significant difference was observed for AD, TM, and ISP fatigue during flexion. In the patients, UT was fatigued while the LS was spared opposite to the pattern seen in controls. In both patients and controls SA and AD were the muscles that showed the greatest extent of fatigue [Table 7 – 1 and Figure 7 – 2A].

In the patients, all muscles showed some degree of fatigue except RM and TM during abduction. In controls, RM, TM, ISP, and SUBS showed no negative slope values. Overall, LT, SA, AD and MD were highly involved within their muscle groups and almost matched in degree of fatigability between patients and controls. While patients showed similar degree of fatigue in LS and UT, controls showed similar finding for LS but not for UT. A difference between patients and controls was noted in the level of muscle fatigue but it was not statistically significant [Table 7 - 1 and Figure 7 – 2B].

The isometric external rotation fatigue task reflected a tendency towards higher levels of fatigue in patients than controls which was in contrast to the other three fatigue tasks. The SP muscles had the minimal effect of fatigue among other muscle groups in controls, while the same muscle group showed considerable involvement of the LT and RM in patients. The HHC group showed lower fatigue in patients than controls, although the highly fatigued muscle in patients and controls was the ISP and appeared with more negative slope value than that of controls. The deltoid group showed a similar pattern but with higher fatigability in controls than patients. No significant difference in the fatigue pattern of all muscles within different groups was detected except for the SA (p<0.05). Although the SA had no negative slope tendency in patients and in controls, a significant difference existed [Table 7 – 1 and Figure 7 – 2C].

During the internal rotation task, the UT was the highly affected muscle within the SP muscle group in patients and controls. It was the only muscle affected in SP muscle group of patients, but changes due to fatigue were evident for UT, LT and RM within the SP group in controls. The HHC group revealed great difference between patients and controls with SSP, whereas ISP and SUBS were the most fatigued in controls. The deltoid reflected similar pattern in patients and controls with slight increase of fatigue in controls. Although there was a difference between the muscles of different groups but it was not statically significant [Table 7 – 1 and Figure 7 – 2D].

Table 7 - 1: Mean muscle fatigue of 15 shoulder girdle muscles presented as medium frequency slope (%/min) for female impingement patients and controls at 25% maximum voluntary contraction (MVC) and during 50 seconds of isometric flexion, abduction, external rotation and internal rotation. Bold *p* values are statistically significant (p<0.05).

Muscle Groups	Muscle	SIS Patients		Control		*p* value	SIS Patients		Control		*p* value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
		Flexion					Abduction				
Scapular positioning	LS	0.02	9.00	-2.74	9.74	0.38	-4.53	8.87	-4.26	6.53	0.98
	UT	-1.34	11.69	1.32	9.60	0.36	-4.33	6.80	-1.10	10.30	0.42
	LT	-2.41	10.76	-6.47	5.57	0.22	-9.56	9.61	-9.07	9.13	0.91
	SA	-6.23	20.77	-17.06	10.81	0.34	-9.63	10.38	-8.03	13.35	0.95
	RM	-1.17	17.35	-10.07	40.10	0.32	0.21	15.06	1.59	31.19	0.96
Humeral Head Centring	LD	-1.42	28.10	-10.95	16.05	0.22	-7.62	7.08	-6.56	20.78	0.59
	TM	0.98	14.53	-14.80	9.19	**0.00**	2.74	16.14	1.45	14.15	0.53
	PM	-0.92	14.76	-5.29	13.07	0.43	-7.65	14.28	-0.35	24.54	0.53
	BB	-9.58	10.05	-6.58	12.19	0.29	-6.07	10.21	-6.44	14.62	0.98
	SSP	-7.81	10.18	-12.81	20.71	0.46	-4.35	21.10	-11.41	18.55	0.34
	ISP	-7.09	15.04	-21.78	10.15	**0.01**	-14.16	23.11	0.71	27.81	0.48
	SUBS	-7.78	12.12	-3.20	21.61	0.19	-3.09	21.82	0.23	14.41	0.36
Deltoid	AD	-11.90	6.28	-17.06	6.34	**0.04**	-12.51	5.64	-14.63	9.79	0.98
	MD	-9.25	10.67	-15.70	6.77	0.10	-11.97	7.57	-14.78	7.87	0.37
	PD	-6.98	12.02	-13.32	7.02	0.17	-10.12	11.28	-10.29	8.61	0.91
		External rotation					Internal Rotation				
Scapular positioning	LS	5.51	14.87	8.68	23.83	0.87	9.09	21.23	8.36	36.02	0.29
	UT	7.19	12.78	3.37	15.87	0.33	-7.32	17.78	-6.59	16.60	0.86
	LT	-6.06	23.16	-1.89	7.82	0.44	7.57	39.46	-3.39	15.06	0.86
	SA	1.53	9.69	24.96	40.43	0.03	7.07	26.10	0.18	17.49	0.71
	RM	-4.41	13.78	9.67	29.40	0.24	0.46	21.87	-3.34	14.59	0.19
Humeral Head Centring	LD	4.39	26.09	-4.92	12.11	0.60	10.04	37.79	3.62	22.08	0.54
	TM	-5.26	13.77	0.00	12.52	0.33	-2.91	37.11	1.67	11.00	0.08
	PM	3.71	23.88	-4.75	10.48	0.16	7.24	30.33	-2.49	9.19	0.31
	BB	-1.32	10.24	-2.56	7.23	0.98	-5.82	8.47	-1.89	5.74	0.14
	SSP	-1.41	12.28	2.26	12.17	0.45	-1.91	21.42	-17.53	28.20	0.31
	ISP	-9.02	8.94	-8.05	8.77	0.66	2.15	14.23	-6.93	9.33	0.28
	SUBS	0.86	9.04	-2.27	14.73	0.08	-3.64	10.72	-9.95	35.80	0.59
Deltoid	AD	12.12	26.40	6.29	25.84	0.39	-2.81	9.11	-5.77	8.92	0.43
	MD	-4.99	14.38	-6.82	10.73	0.80	-6.55	16.55	-9.42	6.44	0.97
	PD	-3.21	7.44	-5.11	11.24	0.39	-6.33	17.87	-7.56	12.30	0.86

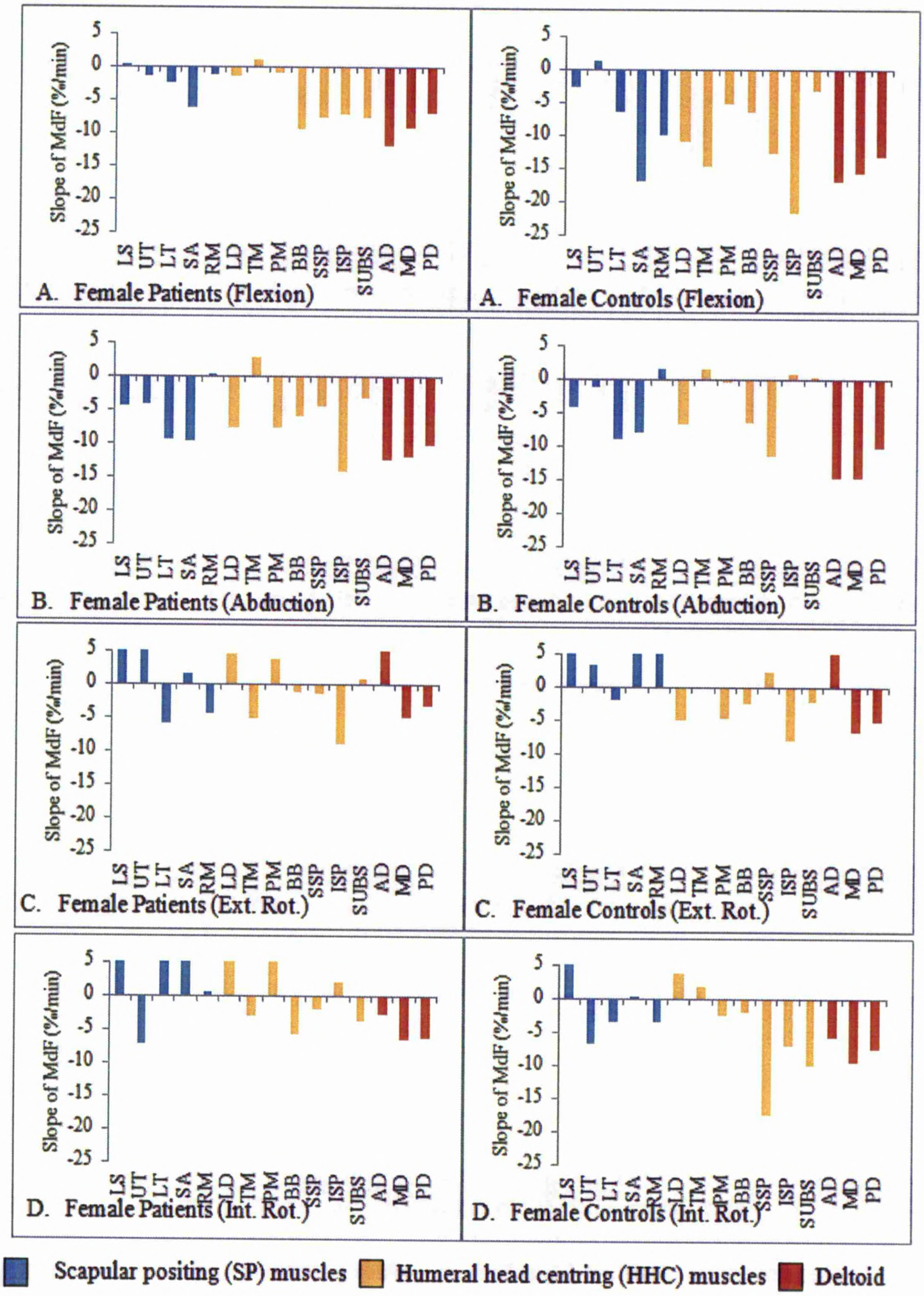


Figure 7 - 2: Isometric muscle fatigue contraction at 25% maximum voluntary contraction (MVC) for 50 seconds. The vertical axis indicates the slope (%/minute) and the horizontal axis indicates shoulder muscles within muscle groups.

7.2 Muscle Fatigue in Male Participants

In general, patients developed less fatigue compared to controls in all tests. During isometric flexion, patients showed fatigue involvement of all SP muscles, particularly SA. In controls, the RM was the most affected muscle followed by SA and LT, while the LS and UT had lesser fatigue than that observed in patients. In patients and controls, all HHC muscles were fatigued except SUBS in patients, though it was fatigued to a greater extent in controls, followed by ISP and TM. The deltoid components were all almost equally fatigued in patients, while in controls AD had the highest fatigue followed by MD. The significant difference was found only for TM and AD [Table 7 – 2 and Figure 7 – 3A].

During abduction in the scapular plane, all muscles except LS showed a variable extent of fatigue in controls. Within the SP group the highest fatigability was observed in SA followed by LT and RM in patients and controls. The HHC group showed more involvement of BB, SSP, ISP and PM in patients, while the ISP, SSP, TM were more prominently involved in controls. PM showed considerable fatigability in patients compared to minimal involvement in controls. Within the deltoid group, highest fatigue was observed in PD followed by MD in patients, while the MD followed by AD were highly affected in controls. A significant difference between patients and controls was found for AD and MD ($p<0.01$) [Table 7 – 2 and Figure 7 – 3B].

During isometric external rotation fatigue task, patients demonstrated more fatigue than controls in contrast to the other three tasks which was similar to the pattern described in female patients. The SP group showed utmost involvement of the RM followed by LT in both patients and controls. The largely affected muscles in HHC group were the ISP and TM in patients and controls. The AD, MD and PD were obviously showing an inversely proportional relation between patients and controls. No significant difference was observed between the different muscle groups [Table 7 – 2 and Figure 7 - 3C].

During the isometric internal rotation task, the UT was the only affected muscle by fatigue within the SP muscle group in patients, while in controls it was the most affected in addition to the involvement of all other SP muscles. The HHC group revealed less involvement in patients than controls, with SSP being the highest fatigued muscle in both groups. Within the deltoid group, MD showed a minimal degree of fatigue in patients while being the most affected in controls. LD in patients and SUBS in both patients and controls did not show the progression of fatigue. A significant difference of fatigue was noted between patients and controls for LS, LD and SUBS ($p<0.05$) in addition to MD ($p<0.01$) [Table 7 – 2 and Figure 7 – 3D].

Table 7 - 2: Muscle fatigue of 15 shoulder girdle muscles presented as medium frequency slope (%/min) for male impingement patients and control subjects at 25% maximum voluntary contraction (MVC) and during 50 seconds of isometric flexion, abduction, external rotation and internal rotation. Bold p values are statistically significant (p<0.05).

Muscle Groups	Muscle	SIS Patients		Control		p value	SIS Patients		Control		p value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
		Flexion					Abduction				
Scapular positioning	LS	-3.72	8.16	-1.64	8.92	0.88	-3.42	12.35	5.23	16.62	0.20
	UT	-5.22	8.13	-0.33	7.88	0.28	-4.32	7.72	-7.89	6.94	0.09
	LT	-7.75	7.40	-10.22	8.35	0.25	-8.85	8.39	-10.89	7.63	0.23
	SA	-8.91	12.24	-15.57	10.59	0.10	-10.95	10.20	-15.15	10.37	0.27
	RM	-3.07	30.13	-18.45	35.16	0.15	-8.73	17.93	-9.54	20.50	0.81
Humeral Head Centring	LD	-2.63	26.42	-12.53	19.66	0.14	-6.69	11.74	-3.76	25.99	0.79
	TM	-4.39	8.37	-17.20	13.8	**0.00**	-3.73	14.95	-9.67	17.39	0.22
	PM	-3.77	10.75	-8.69	14.11	0.41	-10.00	10.15	-0.71	25.55	0.49
	BB	-5.88	7.89	-4.68	8.43	0.63	-13.06	16.06	-6.18	12.42	0.22
	SSP	-4.33	21.50	-8.01	37.23	0.38	-11.57	26.71	-10.56	18.75	0.64
	ISP	-17.33	24.85	-16.83	15.85	0.88	-10.47	20.12	-15.58	23.13	0.32
	SUBS	0.25	32.75	-23.26	30.55	0.09	-7.28	22.52	-8.87	24.95	0.77
Deltoid	AD	-9.34	10.37	-20.37	11.57	**0.01**	-9.11	7.83	-18.99	11.43	**0.00**
	MD	-9.76	6.25	-15.16	10.39	0.08	-10.75	7.43	-20.72	9.44	**0.00**
	PD	-9.95	13.29	-8.90	12.36	0.86	-13.36	12.05	-13.55	8.00	0.79
		External rotation					Internal Rotation				
Scapular positioning	LS	3.19	7.79	5.82	27.87	0.50	12.47	19.69	-1.59	12.26	**0.04**
	UT	1.74	14.91	3.23	15.16	0.63	-1.68	11.19	-10.45	23.47	0.08
	LT	-2.42	9.37	-3.06	11.07	0.76	4.67	22.04	-2.78	23.59	0.13
	SA	8.90	17.95	12.91	44.71	0.48	3.83	18.24	-5.34	17.67	0.08
	RM	-6.30	11.71	-3.57	12.02	0.69	20.86	73.49	-6.41	13.31	0.13
Humeral Head Centring	LD	7.16	20.44	-2.02	23.01	0.15	6.43	27.26	-4.62	25.31	**0.04**
	TM	-12.26	16.48	-14.04	17.96	0.85	-4.99	11.63	-7.74	9.82	0.24
	PM	4.86	12.37	5.98	25.98	0.30	-0.59	18.78	-9.65	9.21	0.13
	BB	-9.55	13.78	-3.60	17.38	0.10	-0.69	15.71	-2.20	9.63	0.95
	SSP	1.40	14.35	-3.40	19.56	0.63	-9.75	29.35	-16.55	33.07	0.52
	ISP	-15.83	21.40	-14.07	16.55	0.90	-1.06	21.78	-5.43	10.08	0.80
	SUBS	-6.00	27.94	-4.07	22.96	0.87	3.48	14.95	6.09	53.59	**0.02**
Deltoid	AD	-2.65	13.49	-3.94	17.55	0.85	-4.72	13.75	-8.36	16.83	0.36
	MD	-3.78	9.49	-3.12	14.19	0.74	-0.69	16.07	-14.62	9.42	**0.00**
	PD	-5.07	9.30	-3.05	10.16	0.90	-4.53	15.64	-11.50	10.23	0.18

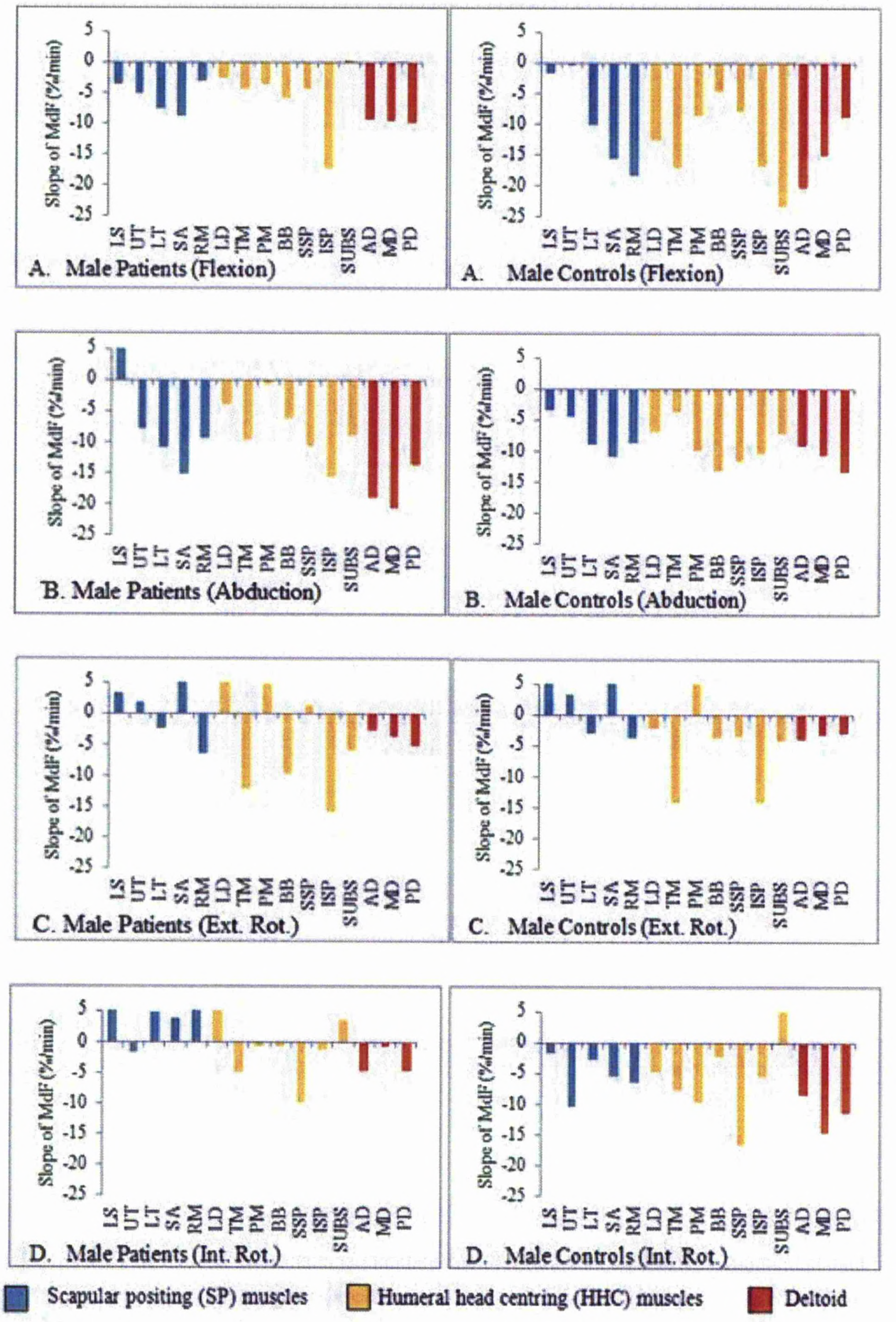


Figure 7 - 3: Isometric muscle fatigue contraction at 25% maximum voluntary contraction (MVC) for 50 s. The vertical axis indicates the slope (%/minute) and the horizontal axis indicates shoulder muscles within muscle groups.

The fatigue protocol aimed to measure and compare the fatigability of 15 shoulder muscles in SIS patients and controls during a submaximal voluntary contraction (25% MVC) as described in the methods chapter (chapter 3, section 3-7) during four distinct movements of the shoulder: forward flexion, abduction, external and internal rotation.

8 CHAPTER EIGHT: DISCUSSION

8.1 Introduction

This is the first study on a total of 72 patients with SIS and healthy controls of both genders that included several clinical and functional parameters, in addition to EMG study of 15 shoulder muscles during simulated dynamic cycles of daily living activities and fatigue protocol. An extensive data acquisition has been managed to provide a safe, accessible and valuable database for further interpretation, analysis and future plans.

Based on history taking and clinical examination the participants were recruited and appointed for series of objective and subjective clinical assessments and EMG protocol in order to test our three-part hypothesis. The patients with SIS have significant alterations in scapular position and motion, abnormal muscle strength and patterns of activity, and increased fatigability leading to physical and mental disability. Most of the influencing factors are preventable and reversible with rehabilitation therapy.

This work is a further contribution to demonstrate the substantial impact that scapular positioning and coordinated motion with humerus has on shoulder function and quality of life as well as the existing role of shoulder strength, mobility and posture in determining the extent of disability with shoulder impingement.

8.2 Participants and Methods

8.2.1 Patient Selection

Painful shoulders form an important part of orthopaedic practice, but their obscurity, uncertain prognosis, and the fact that they present so few definite signs and symptoms, render their classification into types difficult on clinical grounds.[443] The above is statement is still valid and the accuracy of clinical tests described for SIS and other shoulder disorders such as instability or rotator cuff pathologies are useful to rule out some disorders (high sensitivity), however, they mostly fail to detect the specific faulty structure (low specificity)[228,43,244]. This study used a comprehensive combination of objective and subjective assessments in order to identify differences in the upper extremity and shoulder functional performance in SIS patients when compared to healthy controls of the same gender and age group. These measurements included clinical tests, functional capacity of the shoulder, posture, strength, and EMG recording (15 muscles), and a blend of generic and shoulder-specific scores/questionnaires.

Pain, weakness and stiffness are important components in the history of patients with SIS and constitute the basis of the clinical tests which are applicable in the assessment of this pathology[229,444,445,248]. Twenty one clinical tests were divided into three main categories in order to support the diagnosis of SIS and rule out other shoulder pathologies including RC tears, shoulder instability and lesions of the glenoid labrum and long head of the BB muscle. The pain precipitating tests at the painful arc, Hawkins-Kennedy and Neer's sign were mostly positive in female and male patients in this study, followed by tests with combined pain and weakness as with lift off, empty can and full can tests (Table 2 – 2, Table 4 – 4 and Appendix I and III). Our approach to the patients with SIS was similar to that reported by Cools (2008)[446] (Figure 2-1). Though Naredo and Aguado (2002)[274] concluded that physical examination had 72.7% of specificity in SIS, Calis et al. (2000)[249] and Park et al. (2005)[43] reported a higher specificity up to 88.8% in at least 3-6 test combinations. The diagnosis of recruited patients in the present study was further supported either by the arthroscopic assessment during subacromial decompression or by their good response to physiotherapy.

8.2.2 Muscle Strength (Isometric Maximum Voluntary Contraction)

Weakness is an important issue in SIS patients and quantification of muscle strength is essential in functional assessment, clinical management and during follow-up. Isometric MVC is an objective index for muscle strength which has been used widely in relation to shoulder conditions. Participants in this study were both actively encouraged and provided with visual feedback during the strength measurement to enable them to produce the maximum force generation they able to tolerate. Participants performed isometric MVC during 4 classic distinct shoulder movements i.e. forward flexion, abduction, external and internal rotations using the Nottingham Mecmesin Myometer[424]. Walton et al.(2007)[424] investigated the validity, accuracy and reproducibility of Nottingham Myometer to a modified fixed spring balance[425], and concomitant changes in constant score in 108 patients with rotator cuff disease. They reported no significant difference by the two tools for muscle strength measurements. Although the use of electronic measuring devices has been advocated as more accurate, we took into consideration not only the accuracy in the device selection but also the screen display and visual feedback impact on the patients and controls. Park et al. (2008)[447] assessed shoulder muscle strength in 153 patients with SIS, before and after SIS anaesthetic test. He used the Nottingham Mecmesin Myometer for strength measurement during scapular plane abduction, internal and external rotation from neutral position[447]. Pain and weakness are related symptoms and well known as pain fear[448,449,290] or pain-inhibited weakness[450,234], and further consideration was given to eliminate their impact on strength measurement and the implications for the interpretation of results. A limitation in muscle strength assessment was that the elevation of the arm to 90^{0} was painful and could affect muscle strength. A recorded lower, less painful elevation was allowed to measure strength without stress[278].

8.2.3 Range of Motion

The ROM was measured using the goniometer for 5 standard movements of the shoulder including flexion, extension, abduction, horizontal adduction and external rotation in standing position. For external and internal rotation some authors[451] recommended their assessment with shoulder abduction to 90^{o}[451,452]. The shoulder abduction to that extent is provocative and unreliable for patients with shoulder pain[55]. The controls and patients in this study were examined for external rotation with the arm in neutral position (0^{0} abduction) to avoid discomfort. Regarding the internal rotation, even in neutral arm position the body limits the full range of rotation; therefore, we assessed the participants' ability to place the hand behind their back as recommended by the American Academy of Orthopaedic surgeon and the Society of American Shoulder and Elbow Surgeons[453] and commonly used with the Constant-Murley score[278]. It is usually described by the patients with impingement as a painful restriction when they attempt to approach their back for dressing, attending to personal hygiene, and during other activities of daily living

8.2.4 Posture

Some authors have suggested that alterations in scapular positioning influence the function of the shoulder[18]. These alterations lead to scapular instability and impairment of sufficient muscular force generation in the scapulohumeral muscles which are crossing the GHJ and normally preserve stability during shoulder motion[102]. In addition, patients with SIS are usually informed and advised on the significant impact of faulty posture and muscle imbalance in the pathology of SIS[454,113]. The present study measured the scapular positions bilaterally and as a single axial measurement for each thoracic curvature, neck and shoulder positions in all patients and controls in the study. The participants' position, reference points and techniques for measuring the resting position of the scapula as normalized scapular protraction (NSP) and scapular index (SI) as well as forward head (FHP) and shoulder (FSP) positions were similar to those reported on 60 controls and 60 patients with SIS by Lewis et al. (2005)[103], who tested the reliability of the techniques separately on 15 individuals. Their findings did not support significant differences between patients and controls and correlations with clinical presentation. DiVeta[429] also reported no correlations between NSP and performance of selected scapular muscles.

The used above NSP and SI measurements were applied at rest measuring the 'resting position of scapula', therefore the need to identify the scapula in different positions with the elevation of the arm helps to assess the stabilizing effect of the muscles acting on the scapula as the levator scapulae, trapezius, serratus anterior, rhombois, latissimus dorsi and pectoralis minor. The lateral scapular slide test (LSST) allows to measure the distance between the inferior angle of the scapula and the closest thoracic spinous process with the arm at 0°, 45° and 90° abduction in scapular plane[18]. According to the original description of LSST by Kibler (1998)[18], the results were obtained by calculating 'the difference' between the distance on the affected side and unaffected one. We emphasized that the unaffected shoulder was not a reference for normality. Earlier, Gibson et al. (1995)[455] investigated the scapular position at rest and found poor reliability with comparisons based on the difference between sides and better reliability with use of distance between the inferior angle of the scapula and thoracic spinous process at the same level. Several other researchers[456,457] challenged the specificity and reliability of Kibler's technique. Koslow et al. (2003)[456] reported high variability in the scapula resting position between sides and the use of kibler's original LSST had low specificity of 26.8%.

In the current study, we obtained the mean distance between the inferior angle of the scapula and the thoracic spinous process at the same level, not the difference between sides, for comparisons with controls at each position. Sometimes, it was difficult to trace the inferior angle because of fatty subcutaneous tissues; therefore, we tried to move the arm horizontally forward and backward until the inferior angle was palpable.

Lastly, the thoracic spine curvature was measured using a flexicurve ruler between C7 and T12 spinous processes [Figure 3 – 4]. The technique is used to measure the length and height of the thoracic kyphosis, from which the thoracic kyphosis index (TKI) is calculated. The higher index value means increased anterior curvature of the thoracic spine. Lundon et al. (1998)[427] compared the flexicurve to DeBrunner's kyphometer and roentgenographic results and reported no significant difference in the reliability of all three instruments. Chow and Harrison (1987)[458] used the Flexicurve ruler and observed that fitter individuals with normal bone mass have significantly lower TKI. Yanagawa et al. (2000)[428] used the same technique to measure TKI on 26 osteoporotic females. The flexicurve is feasible, available and convenient. The major limitation is the possibility of changes in shape once removed from its contact with the spine, and this should be overcome by careful removal and immediately get a drawing line of the thoracic curve on a paper with clear marking of the levels C7 and T12.

8.2.5 Functional Impairment Tests-Hand and Neck/Shoulder/Arm

It is believed that the shelving system and simple to difficult multi-level tasks with 1 kg weight in hand, is feasible, reliable and reproducible in patients with mild to moderate SIS. Stopping criteria were clearly defined for patients whose endurance might be challenged with pain, stress or fatigue. Furthermore, these tasks explore the entire upper limb activity rather than just the shoulder. This is in accordance with the kinetic chain theory[459,460] which suggests the ability to perform activities of daily living relies on the functional capacity and integrity of the shoulder, elbow, wrist and hand. The protocol used in the current study to assess the upper limb performance without using EMG assessment was similar to that originally described by MacDermid et al. (2007)[58] for FIT-HaNSA. Healthy controls were able to finish the three tasks but few showed progressive discomfort during EDT and stopped within the last minute. The participants also attempted a change in the arm position during the last two tasks, therefore we kept encouraging and advising them to maintain arm movement as normal as possible and to stop if pain was severe.

8.2.6 Self-Reporting Questionnaires

We decided to have a wide idea about the participants' perception to their shoulder function specifically and their health and quality of life generally. The subjective assessment included two shoulder specific scores (CMS[278] and OSS[421]), two Upper extremity functional scores (DASH[285] and ULFI[287]), one general health SF-12(GH SF-12[422]) and one psychology scale (HADS[288]) and finally a questionnaire for pain character and intensity (MPQ[298]). No difficulties were faced in any of the questionnaires except in MPQ when some patients were not familiar with the terms used for characterizing the pain. Even though the clarification of the terms was provided, the patients still expressed their displeasure. The participants, who attended the study in two sessions, were allowed to complete the questionnaires at home and bring them in the next session.

Regarding the scoring of the shoulder-specific tools, the CMS[278] and OSS[283] had different scoring system from others. The CMS was originally had the lowest score for most severe presentation (worst condition) and the highest score (100) for normal presentation (Best condition), while the OSS was modified by Dawson et al. (2009)[283] to have individual score of 0 (the worst) and 4 (the best) with a final total score of 48. These shoulder-specific scores are very informative in assessing the shoulders of patients with SIS. In contrast, the other questionnaires had reversed scores with the lowest score reflects (the least suffering) and the highest one indicates the worst condition. At this level of our study and because the components of CMS were very informative we decided to include the results of those components, while other questionnaires were represented with their total scores.

8.2.7 Electromyography

EMG has been comprehensively used to investigate shoulder muscule activity since the classic study by Inman et al.[4] when examined planar shoulder movements. The EMG assessment of upper extremity movements which simulate daily living activities and using all segments of the upper limb kinetic chain without joint restriction are very limited. There have been few studies of multiplanar dynamic muscle activity such as conical shoulder motion[373], eccentric tasks[355], and external rotation perturbations.[355] The current study used a combination of EMG and a modified version of the shelving system described by MacDermid et al. (2007)[58] with an additional internal / external rotation task[374] to assess muscle activity pattern during dynamic cyclic activities in different levels. The patient's activity was tested at waist level, up to 40 ° -50 ° of arm flexion / abduction and finally up to 90°-100° forward elevation and lowering with 1kg of load, which was a challenging level for the patients because of the pain at mid-range of elevation. For the first time, the investigators in the current study used 'microphone sensors' attached to the shelves. The sensors help to maximise the proper timing of the cycles, the exact shelf contact moment and the synchronisation of the video recordings.

The interpretation and analysis was carried on the normalized data to mean amplitude and time[345]. We did not use the raw data for analysis and comparisons though personal observations emphasized their importance as reported in literature[48]. Thus, we propose their analysis and the identification of important differences from normalized data analysis in the future. Furthermore, the EMG data was collected on the overhead task (OHT) as described by MacDermid during 60 seconds but we could not show their results due to a technical limitation as the task included 3 phases rather than 2 which could not be fitted with the Noraxon software[345] and their interpretation required more time than available. We intend to do further analysis and interpretation of OHT data. It is also important to consider a dynamic full task that starts at shoulder neutral position to end with overhead reaching and back to neutral with different reasonable loads. The proposed task will allow complete exploration of the functional arc of the arm.

Finally, the analysis of EMG data with the use of synchronized video recording was very helpful and can be improved by the use of 3-D tracking sensors[19,461,116] recorded very simultaneously with EMG signals during activity.

8.2.8 Fatigue

The use of submaximal isometric voluntary contraction (25% isometric MVC) with EMG recording and the facility of feedback display on computer screen which was provided with the use of Mecmesin digital dynamometer[424,447] was very informative and well controlled. The limitation was in obtaining the isometric MVC which was influenced by the intensity of shoulder pain in the patients. The effect of pain reduced the calculated 25% of isometric MVC[376,10], but still we have sufficient to provide a real picture upon the extent of fatigue in our patients with painful shoulders, add the encouragement from our side and their enthusiasm allows reliable collection of data.

Submaximal isometric voluntary contraction is a popular technique for muscle fatigue assessment[376,10], but with the investigation of normal daily-like activities, we believe that the assessment of dynamic muscle fatigue[462-464] will tell us more about muscle endurance during normal daily activities and work that can be utilized in the rehabilitation of the patients.

8.3 Clinical and Functional Assessments

8.3.1 Objective Assessments

8.3.1.1 Muscle Strength (Isometric Maximum Voluntary Contraction)

Gender related differences exist in muscle strength documenting men stronger than women by age[465,137,145] and there was no significant correlation between strength and range of motion[138]. Murray et al. (1985)[137] reported that women had 45% to 66% muscle strength of that in men and both revealed no significant effect of arm dominance on strength values. On average, women at all age groups tend to be relatively weaker than men; however, these differences are accounted for by differences in muscle mass and muscle quality and muscle fibre contractile function in women and men[236].

In our study, healthy females and males had highly significant difference in muscle strength of the assessed four muscle groups. The women's strength of shoulder flexors, abductors, external rotators and internal rotators was 65%, 67%, 70.5% and 70.8%, respectively of that in men (Appendix VII: Table 1). Both female and male controls showed similar pattern of highest muscle strength in internal rotators and lowest in shoulder abductors as well as external rotators appeared stronger than shoulder flexors. Several studies reported the highest strength for internal rotators[133,466,138] and shoulder flexors were stronger than abductors in healthy people of comparable age group, though the methods of assessment and units were different[145,103,467].

The association between physical capacity (i.e. muscle strength and mobility) and upper extremity musculoskeletal disorders have been reported in studies[468,235,469]. The alterations of shoulder stability, mobility and function performance are attributed to deficits in strength of specific muscles and reduced ROM as a key outcome measures when evaluating SIS[58].

Both female and male patients, in current[work, had highly significant deficit of strength when the affected shoulders were compared with healthy shoulders of female and male controls, respectively. The most affected muscle group was the shoulder abductors as reduced by 51% in female patients and 38% in males, followed by the internal rotators; while the least affected muscle group was the external rotators as reduced to 33% in female patients and 23% in males (Appendix VII: Table 1) .

The superficial deltoid muscles and the deeply seated rotator cuff provide a smooth trajectory of the head of the humerus during arm elevation[4,125]. This relationship was defined as 'a force couple mechanism' by Inaman et al. (1944)[4] (Chapter 2, Section 2.19.7.1.2.). The force couples associated with elevation of the arm have two components. (1) A coronal plane force couple between deltoid and supraspinatus muscles superiorly and the lower elements of the rotator included the infraspinatus and subscapularis muscles which act as depressors to the humeral head, and (2) a transverse force couple between subscapularis anteriorly and infraspinatus/teres minor posteriorly[470-472]. Additionally, within the coronal force couple itself, the supraspinatus was reported to reveale an earlier activity than the deltoid and inferior components of the rotator cuff in order to assist concavity compression and centring humeral head on the glenoid during the first 30°-60° of arm elevation[473-475]. The major deficit in the strength of shoulder abductors, in our study, does not only reflect the involvement of the deltoid and supraspinatus muscles – the supraspinatus muscle is the most vulnerable to insult within the subacromial space[77,46], but also the other components of the rotator cuff[10]. Reddy et al. (2000) [10] found, in patients with SIS, a reduced EMG activity of the infraspinatus and subscapularis muscles during arm elevation from 30°-60°.

The next significantly affected muscle group, in this study, was the internal rotation strength which was more affected than forward flexion and external rotation. That deficit in internal rotation strength contradicts with the findings in literature. Because of the muscle involvement of supraspinatus followed by infraspinatus in the pathology of SIS[476,477] major reduction in abduction and external rotation strength were frequently reported,[478] while there are contradictions in literature regarding the reduction of internal rotation strength[447,479].

Recently, Marcondes et al.(2011)[478] used a hand-held dynamometer to assess muscle strength of 48 patients with unilateral impingement of equal number of both genders and within the age range of 35 to 65. They observed that all symptomatic shoulders had significant reduction of strength with arm elevation in the scapular plane and lateral rotation as compared to asymptomatic shoulders, while reduction in medial rotation strength only found in the age range of 50 to 65. MacDermid et al.[240] conducted a study to determine the reliability of different methods of strength measurements and self-reporting measures. Twenty-four men and twelve women (mean age, 43.6 years) with chronic rotator cuff tendinitis or impingement were compared to 28 men and 20 women (mean age, 40.8 years) without shoulder problems. LIDO dynamometer was used to determine isometric and isokinetic strength of the shoulder rotators. Isometric strength was measured in a neutral internal/external position. They found all shoulder rotation strength measures were predictive of disability, with isometric external rotation strength being the most predictive, and they provide reliable information on the functional integrity of the rotator cuff muscle which is significantly related to patients' function and quality of life. Park et al. (2008)[447] also found, before the impingement test, the abduction in scapular plane with the thumb down was mostly reduced followed by the external rotation and internal rotation was the least affected.

On the other hand and with the increased attention on the role of the scapula in the pathogenesis of shoulder impingement, Smith et al. (2002,2006)[480,481] investigated the effect of scapular protraction and retraction on the forward arm elevation strength in 2002, and scapular protraction on internal and external rotation strength in 2006. In the first study[480], they evaluated 10 healthy subjects and found that forward elevation strength was reduced by 30% with scapular retraction and 23% with scapular protraction. In the second study[481], they evaluated 20 healthy subjects and found that protraction significantly reduced internal rotation strength by 13% to 24% relative to neutral scapular position, while the effect on external rotation strength was more position-dependent, increasing strength by 6% in the internal rotation position and decreasing it by 7% in the neutral position and 20% in the external rotation position. In conclusion of both studies, they stated that changes in scapular position affect shoulder isometric strength. In spite of the methodological differences in above studies, we found some support to the pattern of statistically significant reduction in shoulder strength and postural relevance, as our results demonstrated interesting changes in FHP and FSP in the studied patients as discussed in the next section on posture.

Though investigators have not yet determined whether muscle imbalance is a contributor or result of impingement[16], the pathomechanics of functional impingement involve weakness and muscle imbalance that may start with one either the scapular rotators (Figure 2-3) or deltoid/rotator cuff muscles (Figure 2-4) but for sure eventually both muscle groups are affected[26,18,10,3], leading to alterations in scapular position and motion, reduction in tension-force generation, narrowing of subacromial space and impingement of subacromial soft tissues. Therefore, the potential adverse effects of scapular alterations on shoulder strength should be considered during the evaluation and treatment of patients with impingement.

The unaffected shoulders in both genders of the patients revealed a trend of less strength in the muscle groups but none of them had significant difference from that of controls [Table 5-1 and 5-4]. Hughes et al. (1999)[145] emphasized the importance of having unaffected shoulders' data for comparison in patients whose shoulder deficits manifest with bilateral involvement. We did not agree with the argument by Hughes et al.[145], since the unaffected shoulders are not normal shoulders and comparing unilaterally affected shoulders with contralateral shoulders can lead to bias in outcomes. Though in the current study, the comparison of unaffected shoulders with controls showed no significant difference in muscle strength, there were significant differences when other parameters as the ROM and functional impairment test compared [Table 5-1 and 5-4] which supports early changes in unaffected shoulders.

Furthermore, Hbert et al. (2002)[482] found similar 3-D scapular attitudes between symptomatic and asymptomatic shoulders of subjects with unilateral SIS and both were different from healthy subjects. They attributed the findings to inappropriate neuromuscular strategies affecting both shoulders. Lastly, all patients in this study with bilateral SIS described it as a unilateral start then progressed gradually to bilateral impingement. Therefore, in patients with unilateral SIS, it is important to consider the possibility of their progress to bilateral impingement during evaluation and rehabilitation[483].

8.3.1.2 Range of Motion

The ROM and its relationship to age, gender and dominance revealed conflicting results[138,137,135]. Gender-related effects on ROM were described with minimal differences by Murray et al. (1985)[137], while Barnes et al. (2001)[135] and Roy et al. (2009)[138] observed greater ROM in women than men, particularly with external rotation.

Generally women have more ROM than men because of physiologic and anatomic factors[137,484]. The healthy female controls showed more range of motion than males when the six standard movements of the shoulder were assessed (Table 4-2 and Appendix VI: Table 1). We observed that the great difference was in the range of horizontal adduction and external rotation. Published data includes wide variation of normal ROM particularly in extension, abduction, and external rotation of the shoulder complex (Appendix VII: Table 4) [485].

Neer (1972 and 1983)[46,81] has repeatedly pointed out that the functional arc of shoulder movement is forward, and that forward flexion is often associated with medial rotation at the glenohumeral joint. Accordingly, we observed that the results of the ROM reflected significant impairment of the functional arc in all patients. As it was evident in muscle strength deficit, our results also appeared consistently with significant limitation of shoulder mobility in both genders at the affected shoulders and to lesser extent at the unaffected shoulders. All patients had significant reduction in all directions except with horizontal adduction which showed no or minimal difference. The range of internal rotation was the most painfully restricted and reduced by 45% at the affected shoulders (Appendix VII: Table 3), followed by external rotation, abduction and flexion.

The limitation of internal rotation have not been considered sufficiently in literature in spite that an important part of our daily living activities requires extension and internal rotation of the shoulder to approach our back[486]. The thoracic kyphosis, FHP and FSP have been reported with increased scapular protraction and anterior tilting, which places the acromion and coracoid process - the lateral and anteromedial borders of the coracoacromial arc - furthermore anteriorly and downwards thus affect the functional arc of forward reaching[487,488,104]. Chronic pain adaptations, repeated micro-trauma and inflammatory reactions lead to soft tissue tightness as in levator scapulae, upper trapezius, pectoralis minor and, pectoralis major [Table 8-1], in addition to fibrotic changes in the GHJ capsule. All may lead to limitation of movements particularly the internal rotation as furthered discussed in the section of posture and combined pain score [Section8.3.1.3. and 8.3.2.2.].

The loss of capsular resilience is commonly associated with impairment of motion. Glenohumeral internal rotation deficit and experimentally induced posterior capsule tightness have also been shown to increase scapular anterior tilting and humeral anterior translations relative to the glenoid, respectively[74,489]. Clinically, the distinction between tightness from the posterior capsule or posterior rotator cuff and deltoid is not yet possible[61] because of low specificity of clinical tests. Warner et al. (1990)[68] and Tyler et al. (2000)[490] demonstrated posterior tightness and GHJ internal rotation deficit in patients with SIS, but both studies were unable to isolate the structural causative factors.

The importance of external (lateral) rotation was quoted from Inman et al. (1944)[4] "...for free and full elevation of the extremity, lateral rotation of the humerus is essential" (p. 5). The elevation of the arm up to the range of 60°-120° associates with narrowing of the subacromial space[60,491] and increased subacromial pressure[99], therefore, humeral external rotation clear the greater tuberosity from the under-surface of the acromion and avoid the compression of subacromial soft tissues[19]. The highly significant reduction in the range of external rotation was evident and next to internal rotation in the current study, which added support to the assumption by Browne et al.(1990)[492] that restricted humeral external rotation lead to SIS. However, no conclusive support is available for that assumption.

The reduction in the range of GHJ elevation is a very common clinical finding in patients with SIS[493,366,19,32]. This may be due, in part, to the pain experienced during elevation. The painful arc[1] was originally described as the mid-range pain with arm abduction, but patients may still have a painful arc of motion near 90° of arm elevation in any plane[494]. In the current study, both flexion and abduction of the arm were significantly reduced by 29.6% and 38.3%6,respectively in female patients; and 22.2% and 27.3% respectively in male patients (Appendix VII: Table 3).

Several studies[32,19,482,495,496] on 3-dimensional shoulder kinematics have investigated STA and GHJ kinematics in healthy population and patients with SIS who presented with constrains in different planes of motion. They have emphasized the role of the scapula in health and impingement conditions. They have described decrease scapular upward rotation, increased protraction and anterior tilt as compared with normal scapular kinematics as scapular upward rotation, protraction / retraction and posterior tilt with arm elevation[123,5,367]. With arm lowering almost the reverse has been noticed[497].

8.3.1.3 Posture

The term 'upper body posture' is frequently used to denote the head, neck, shoulders and thoracic spine alignment[103,55]; and continue to receive increasing attention as an important profile alignment with respect to the trunk[498], when the investigation of the pathogenesis and management of SIS are in concern[103].

Cheshomi et al. (2011)[499] cited the following statement based on Kenall et al. (1993)[500]: "Posture can be defined as the position of all the body segments observed at a specific moment. Adequate posture occurs when the body is kept in balance with the least expenditure of energy possible. Under such conditions, muscles work more efficiently and ideal positions are allocated to the thoracic and abdominal organs" (p.1072). Ideal body posture with consistent balanced muscles may not be seen in reality[103], because of variations in the human osseous anatomy, joints static and dynamic stabilizers[501,502,470,503] and environmental influencing factors. Grimmer[504] examined FHP in 427 randomly selected asymptomatic subjects during unconstrained sitting. The plumb-line measurement as described by Kendall et al.[505] was defined as the baseline for ideal posture. No subject demonstrated a resting FHP perfectly aligned with the ideal normal (vertical reference line).

In the current study, healthy subjects of both genders were evaluated for sagittal plane anterior thoracic curvature, head and shoulder positions. The findings of TKI, FHP and FSP [Table 5-1 and Table 5-4] were comparable to those in literature [Appendix VII: Table 1 and Table 2]. Both genders revealed similar findings regarding the FHP but they showed significant higher TKI in male and FSP in female healthy subjects. Page et al. (1997)[506] emphasized the increased thoracic curvature with age and height as 'tall people are prone to increased thoracic curvature'. We found the mean age and mean height of the healthy male subjects higher than that of female healthy subjects [Table 4-1], which may explain the gender difference of the thoracic curvature in healthy subjects. Regarding the FSP, which is known as 'rounded shoulders' in the general community, there is some evidence in the literature that women are more round-shouldered than men[507].

We could not find a difference in FHP between both genders of healthy subjects, though the association of increased thoracic kyphosis with FHP and FSP was anecdotally reported[508,509]. In contrast, quantitative data failed to support an existing relation between the three sagittal components of upper body posture[154,103], and contradictions regarding the resting position of the head in women and men have been reported[507,156,153,487]. For example, Culham and Peat (1993)[487] investigated 57 women over the age of 50, for thoracic kyphosis and scapular protraction; and found significantly greater increase of scapular protraction than in women with increased thoracic kyphosis.

The few conclusive available data [510,154,430,458] (Appendix VII: Table 1 & 2) and variations in asymptomatic subjects makes it difficult to quantitatively define normative data of the head, shoulders and thoracic spine posture, from which deviations can be related to abnormal joint stress and an imbalance of the surrounding musculature[103]. Milne and Lauder (1974)[511] investigated the age effects in thoracic anterior curvature on examining 413 and 406 asymptomatic men and women respectively. No age effect was found in men aged 20-59 years or in women aged 20-49 years. Linear regressions showed an increase in thoracic kyphosis with age in older men and women. Raine and Twomey[154] found no gender difference regarding FHP and FSP between asymptomatic 88 women and 72 men within the age range of 17 and 83 years. They also objectively supported the positive relation between increased age and FHP, but the longstanding assumptions of increased association between increased thoracic curvature and upper cervical spine extension with increased FHP were not supported.

In a person with good upper body posture, elevation of the arm is pain-free through the full range of motion, and the scapula provides a stable base for efficient function of the rotator cuff and other muscle crossing the GHJ[102,512]. On the other hand, a patient with increased FHP, FSP and thoracic kyphosis, the scapula attains an altered position with increased protraction and downward rotation, depressing the acromion, restricting the clearance of subacromial space and increasing the pressure on subacromial soft tissues.[512,123,488,513,481] Now the elevation of the arm is presented with painful mid-range, limitation of motion, muscular weakness and functional disability[103].

Thigpen et al. (2010)[54] investigated the effect of postural changes of the head and shoulder on scapular alterations, using electromagnetic tracking system and surface EMG on eighty asymptomatic volunteers during loaded flexion and overhead tasks. They decided to avoid the possible confounding factor of shoulder pain by recruiting asymptomatic volunteers. In order to establish the criteria for classification, they measured the FHP and FSP angles in 310 asymptomatic volunteers and the mean ± 1 was selected as the border between a group of a good posture and a group with increased forward posture of the head and shoulder. They recorded the changes only in the repeated ascending phase of both tasks. The group with increased FHP and FSP displayed significantly greater scapular protraction with less SA muscle activity in tasks, as well as greater scapular upward rotation and anterior tilting during flexion task. Thigpen and colleagues concluded that increased FHP and FSP impacts shoulder biomechanics independent of shoulder pain.

In the current study, we found, in all patients, a combination of a painful shoulder, muscle weakness, limitation of motion and postural deviations in the sagittal plane. Obviously female patients were more affected than males. Regarding the alterations of posture in the sagittal plane, the female patients had doubled-effect of the greatly increased FHP and FSP, while male patients only had significantly increased FSP. In male patients, the leaning forward mean angle of the head appeared more than that in females with wide SD, though the reverse could be observed in controls of both genders (Table 5-1 and Table 5-4). Thus, the FHP in male patients was expected to have clinical relevance.

Minle and Lauder (1974)[511] reported increased thoracic kyphosis above the age of 49 years in women and above the age of 59 years in men. Therefore, we expected the trend of increased TKI will be of clinical importance with advanced age of the patients in the current study, and females will have earlier changes than men due to anatomical and physiological issues[514-516]

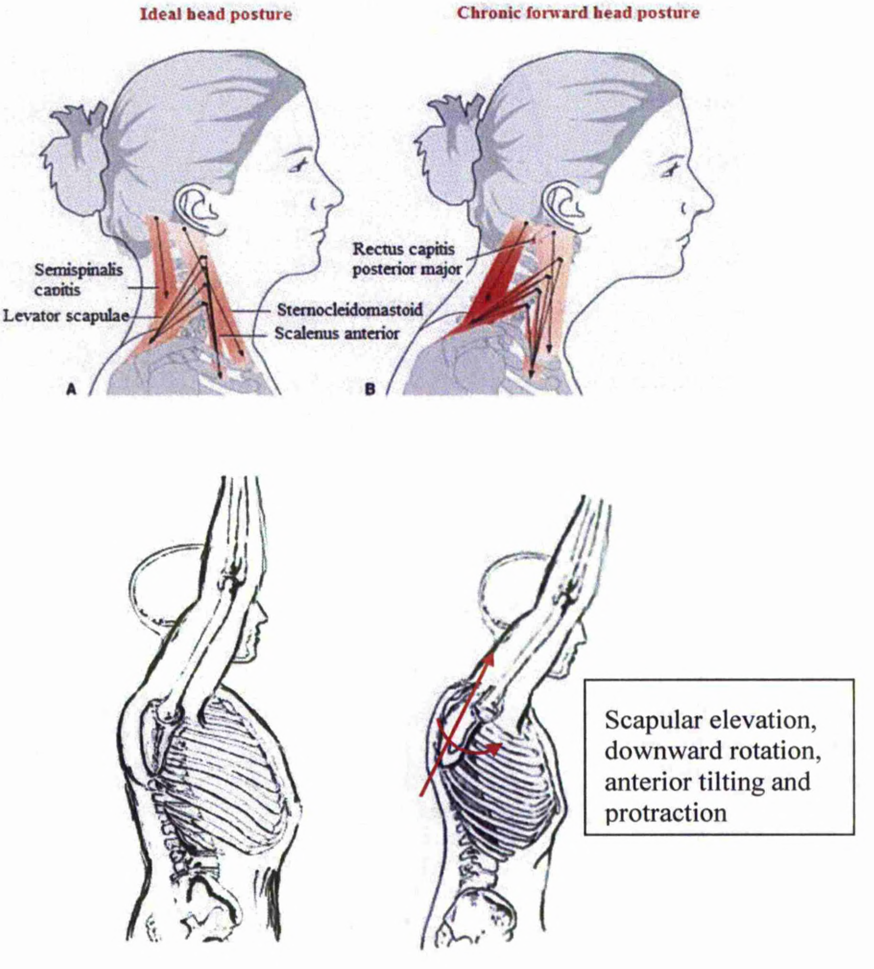


Figure 8 - 1: Deviation of head posture and alterations in muscle action and scapular stability

The changes of upper body posture result in changes in the resting position of the shoulder complex[487], concomitant imbalance of the muscle system activity[48,517,97] and decreased endurance[518,499]. All have been demonstrated in patients with SIS[103,55].

van Duijn et al. (2007)[519] stated that "Prolonged positioning of the head in forward head position and of the shoulders in a rounded position could have resulted in the observed adaptive shortening of the pectoralis minor and major, the upper trapezius muscle, and levator scapulae muscle, and decreased strength of the scapular stabilizing muscles. The muscle weakness and the resulting inability to maintain a corrected posture for any length of time might also have been one of the underlying causes of the patient's postural deficits." (p. 22). Opposing to the described shortening, the altered spine-scapular positions will also influence muscle length and, therefore, influence the ability to generate tension-force[488] leading to further weakness and reduced endurance of the muscles acting on both the scapula and humerus[499]. Table 8- 2 summarizes the effect of deviated upper body posture on the shoulder complex.

Table 8 - 1: Postural effect on scapulothoracic articulation and glenohumeral joint and adaptive changes of the muscular system

Changes in motion and position	Adaptive muscle tightness	Impaired normal motion	Adaptive muscle lengthening and reduced tension-force generation
Scapula downward rotation	Pectoralis minor Levator scapulae Rhomboids	Scapular upward rotation	Upper trapezius Lower trapezius Serratus anterior
Scapula anterior tilting	Levator scapulae Upper trapezius Pectoralis minor Coracobrachialis Biceps brachii	Scapular posterior tipping	Lower traps Serratus anterior Long head of triceps
Scapula protraction (Internal rotation)	Pectoralis major Latissimus dorsi Teres major Subscapularis Anterior deltoid	Scapula retraction (external rotation)	Posterior deltoid Infraspinatus Teres minor
Humerus anterior/superior migration	Supraspinatus Subscapularis Posterior deltoid	Humeral depressors	Infraspinatus Teres minor

From rehabilitation point of view, Kibler et al. (2008)[520] provided further support that specific exercises activate the key scapular-stabilizing muscle are important to control the dynamic scapular motion and stability. With EMG monitoring, they used the specific exercises to activate serratus anterior and lower trapezius muscles at amplitudes that are known to increase muscle strength. Several other researchers[55,521-523] have investigated active correction and taping for faulty upper body and shoulder postures in patients with SIS. Their conclusions emphasized short-term benefits with improvement in function and reduction in pain; and they recommended further research to determine the long-term outcomes of treating muscle imbalances and postural changes with exercises, stretching and taping in patients with SIS.

The scapular position was evaluated in the coronal plane by measuring the NSP, SI and LSST variables. We observed that NSP and SI variables did not reflect any significant difference in both female and male study groups. The mean of NSP was comparable to similar assessment by Lewis et al.[103] and DIVet et al.[429] and they reported no significant difference in symptomatic and asymptomatic subjects, leading these investigators to question the assumption of a linear relationship between muscle control and scapular position in the pathogenesis of SIS. Regarding the SI, though there was no difference between patients and controls of both genders, the mean value was relatively higher in our control groups when compared with the mean reported on healthy subjects by Borstad and Ludewig. (2005)[524]

We used the LSST to assess 'the distance' between the scapular inferior angle and the closest spinous process[18], to compare the position of the scapula at rest, with the arm abducted to 45° and to 90° in scapular plane bilaterally, as previously discussed [Section 8.2.4.]. The only greater reduction was in female patients than female controls when the affected arm was abducted to 90°.

Pain, pain avoidance and weakness can affect the scapular lateral slide with the arm abducted about 90° [525], in addition, increased FHP and FSP lead to increased scapular protraction[481,494,367]. The presence of increased scapular protraction associates with restricted scapular upward rotation when the arm abducted in the range of 60° - 90° [Figure 2-1][9], greatly reduced subacromial space clearance and o increased painful range of arm abduction[481,494,367].

Lastly, the female patients in this study presented with significant reduction of external rotation range and strength. Humeral external rotation is important at the range of 70° – 90° of arm elevation to allow subacromial clearance from the greater tuberosity[99,19,492], while impairment of this action leads to further impingement of subacromial soft tissues.

Regarding the male patients, though they had significant increase in FSP but probably with lesser effect than the case with female patients who had a summated effect produced by both FHP and FSP; additionally, their muscle strength still considerably high, although they had significant decrease in strength. Therefore, the LSST did not reflect differences between male patients and controls.

Although assessment of scapular position is considered to be an important component of the clinical examination of the shoulder, conflicting clinical and research suggest further investigations are necessary.

8.3.1.4 Functional Impairment Test-Hand and Neck/Shoulder/Arm

FIT-HaNSA is a self-reporting tool to assess the shoulder functional performance during simulated daily living activities. The neck, shoulder, arm, elbow, forearm, wrist and hand are important components of the integrated kinematic chain that influence functional performance of the upper extremity[459,526,527]. FIT-HaNSA is used indirectly to assess stability, strength and motion of the shoulder complex as the arm is moving about the functional arc for forward reaching[46,81]. Clinicians and physiotherapists can observe the symmetry and coordination of the shoulder girdle with arm elevation and lowering. Moreover, during the tasks, the participants' perception regarding stress, pain, weakness and satisfaction should be documented.

The discriminative validity of FIT-HaNSA enabled the investigators to distinguish the grades of severity in patients with SIS[58]. The three tasks were placed in three different levels range from the waist to overhead position (Chapter 3: Section 3.6.5). In the current study, all healthy controls were able to complete 5 minutes of WUT, but to lesser extent for the other two tasks. In the EDT, males did better than females which could be related to muscle strength as males were stronger. In OHT females did better which could be explained by the growing body of literature suggesting that females have a greater resistance to fatigue than males[528]. The results are comparable with normal values reported by MacDermid et al. and Roy et al. (Appendix VII).

Regarding the female and male patients, we observed that both had highly significant impairment when compared to respective control groups. The worst impairment was during EDT and the least impairment with WUT. The female patients showed greater impairment, in all tasks generally and with EDT in particular, than male patients. That impairment in female patients was attributed to the following factors: (1) more demanding loaded activity at the eye level in patients who had considerable weakness, (2) challenging the trigger point of pain at the mid-range of painful arc, which was relatively lower in the range due increased FHP and FSP, and (3) increasing discomfort and feeling of insecurity (instability) during early phase of arm lowering. That insecurity was reflected also by the results of EMG, while doing the same task, as an abrupt change in muscle activation pattern and referred as 'shoulder phenomenon' [Figure 6 – 21].

In spite the OHT was in a higher level, patients of both genders scored relatively better than EDT and female patients scored more than males. The OHT was designed to assess endurance during a sustained overhead activity without lifting any weight[58]. The arms in OHT were elevated about 120° when the subacromial space widened again, reduced subacromial pressure and minimized pain.[60] Therefore, OHT was more achievable than EDT because of less pain, less demanding, and female patients were assumed to be more resistant to fatigue than male patients.

The trunk movements were not restricted during the tasks and the participants were instructed to stand in a standardized position[58]. Sitting position and restriction of trunk movement may affect badly normal arm elevation. Normal elevation of the shoulder requires about 15° of thoracic extension for full bilateral arm elevation[529] and about 9° of thoracic extension[530] with unilateral arm elevation[516].

Lastly we observed highly significant relation between FIT-HaNSA and muscle strength in contrast to less significant relation to CPS and pain component in CMS [Table 5- 7]. That reflected the issue of weakness which can be corrected with specific rehabilitation and improve functional performance in patients with SIS.

8.3.2 Subjective Assessments

8.3.2.1 Self-Reporting Questionnaires

Based on the globally interacting factors influence the course of SIS [Figure 2 – 2], the impingement patients, as those with other chronic disorders, are incorporating a wide range of environmental, psychosocial and physical risk factors that may contribute to the severity and complexity of impingement. History taking, physical examination and other investigations; in addition to the patients' personal views and experience on their condition will allow proper decision-making on a specific and individualized treatment approach.

Several self-reporting measures were used to identify the participants' perception on their shoulder problem (CMS and OSS), consequences on the upper limb function

(DASH and ULFI), character and intensity of pain (MPQ), and finally their impact on general health (GH SF-12) and psychosocial (HADS)quality of life. The validity, reliability and responsiveness of the questionnaires have been reported[531,532,287,533,289,534,535].

8.3.2.1.1 Constant-Murley Score and Oxford Shoulder Score

These questionnaires are shoulder-specific self-reporting tools. Generally the female and male controls acquired the highest or nearby scores in CMS and OSS which emphasized the normal shoulder function. The female and male patients had very greatly significant reduction in total mean score of each questionnaire estimated 50-55% of the total mean scores acquired by controls [Table 5–2, Table 5–3, Table 5–5 and Table 5–6]. We used CMS to assess the unaffected shoulders of female and male patients; there was minimal difference in total score. The minimal difference may be considered of clinical importance on long term. We have observed progressive scale from unilateral to bilateral SIS.

The patients showed interesting findings in the components of CMS. We observed that both genders had quite proportional reduction in pain, activity and ROM scores ranged 45 -60% of the respective controls' scores; but quite different for the component of power. As it was previously noted in muscle strength (Section 8.3.1.1), the power – as measured in 90° of scapular plane abduction – presented as 51% and 62% of the power in female and male controls, respectively. Also taking in consideration the abduction muscle strength in female controls was 67% of abductors strength in male controls.

Regarding the position for power measurement at 90° abduction in scapular and the impingement patients with painful abduction, we followed the original recommendations by Constant and Murley[278]: "In patients whose active range of abduction is less than 90°, the power at whatever maximum active abduction can be performed is taken ..." (p. 161). Some authors[536,537] questioned the reliability of CMS as they applied the floor/ceiling effect on the component scoring, for example, patients who were unable to achieve the test position (90° of abduction) had been assigned a strength score of 0, and they claimed considerable floor effect on their results. Furthermore, Roy et al. (2010)[531] in a systematic review on CMS have provided further support for the use of CMS by clinicians and researchers and emphasized the need to re-evaluate and improve the standardization and precision of the major psychometric properties such as content validity, minimal detectable change, and minimal clinically important differences.

8.3.2.1.2 Disability of the Arm, Shoulder and Hand and Upper Limb Function Index

The region-specific questionnaires including DASH and ULFI have reversed scores to those reported with CMS and OSS. The female and male controls had the lowest scores that reflected very minimal or no functional impairment at all. Both groups of patients were very highly distinguished from controls by 45-50 higher score points of pain and functional impairment symptoms. MacDermid et al (2007)[58] used the DASH and Shoulder Pain and Disability Index to validate FIT-HaNSA in impingement patients (11males and 8 females) and controls (11 males and 8 females) with a mean age of 32 ($\pm$12) in each group. The control group in their study and both control groups in the current study scored within the lowest 2% of the DASH scale, while the impingement patients in their study scored about40% less than female and male patients in the current study. The differences between the two studies were due to small sample size, no gender differentiation and younger age group in the study by MacDermid. Concerning the ULFI, the requirement of responding with only 'yes' or 'no' to the 25 items was confusing to participants when they decided a response between the dichotomous options , therefore we think that problem have been solved with the new modification of ULFI reported by Gabel et al.[538] in 2010. The modified version included three-point response with the aim of improving clinimetric properties.

8.3.2.1.3 General Health SF-12 Survey and Hospital Anxiety and Depression Scale

The general health SF-12 survey was very informative on the physical and mental health. Although the control groups reflected minor limitations in general health, the survey was able to differentiate impingement patients with major impairment in the physical and mental component of the questionnaire. Moreover, the mental behaviour was further explored by using the HADS scale which demonstrated highly significant increase of anxiety and depression in patients with SIS. That is giving further support to the assumed relation between different psychological miss-behaviour, fear of pain and inhibitory effect on function which are usually presented in musculoskeletal disorders with chronic pain[450,184,290]. The psychosocial changes should receive great attention in the treatment decision of SIS patients[539].

8.3.2.2 Combined Pain Scores

There is a growing body of research to investigate the relations between pain severity, deficits in strength, limitation of motion, postural deviations and functional disability[55,49,540,541,199 234,450]. The interpretation of different relations reveal wide variations, lack of consistency, ambiguity in the pathogenesis and obscurity of inter-playing clinical and psychosocial factors[234,450,290] in shoulder impingement. Further understanding of assumed interacting causal and precipitating factors provides strong prognostic predictions and guide-lines to the proper preventive and curative plans[312,542].

Using seven items related to pain which were collected from the utilized self-reported questionnaires permitted the application of a combined pain score (CPS) to quantify pain in the patients with SIS and preliminary investigation of overall correlations [Chapter 5, Section 5.3 and 5.4].

We observed from the combination of several patients' responses on pain a wide range of pain severity represented mild, moderate and severe grades in female and male patients [Figure 5-2]. Those with minimum scores informed 'severe pain' and those on the higher side informed 'mild pain'. That inclusive distribution of pain presentation made our data representative to the population with different severities of impingement. It is worth to have future analysis with stratifying the study groups according to pain severity, investigating the involvement of pain fear or avoidance[450,234] and their relation to other parameters included in the current study.

The overall correlation of CPS [Table 5 – 7] reflected significant positive correlation with isometric muscle strength - only in flexors and internal rotators strength, all directions of shoulder motion and functional impairment test. The correlation with postural elements was negative and not significant statistically. Those findings can be related to changes in upper body posture and scapular position[543,55].

The increased FSP – which was demonstrated in all patients in the current study - and associated scapular protraction shifts the acromion and subacromial painful trigger point further anteriorly[544,55]. Additionally, chronic adaptive shortening of levator scapulae, upper trapezius and pectoralis minor muscles with increased FHP and FSP forces the scapula into downward rotation and anterior tilt[519,545,123]. Such changes depress the acromion, narrow the subacromial space and reduce the pain-free range of painful-arc as impingement patients elevate their arms for forward reaching[481,172]. The literature data concerning the shoulder isometric strength and scapular protraction, as previously described in section 8.3.1.1., supports the existing selective reduction in muscle strength. The increased scapular protraction associates with reduction of isometric strength by 23% in flexion[480], 16% in abduction[488], 7% in external rotation[481] and 24% in internal rotation[481]. Thus, the findings in our patients and those in literature supports an association between scapular protraction, pain and selective weakness in SIS.

In the current study, the overall correlation of pain [Table 5-7] as CPS or as an individual component of pain in Constant-Murley score was not able to detect a significant relation with postural elements. Borstad et al. (2006)[546] stated that "One explanation for failing to find a relationship between postural deviations and shoulder pain is that these 2 entities are at the beginning and end, respectively, of a continuum, with movement alterations occurring between them" (p. 550). Furthermore Sahrmann (2002)[547] described that postural deviations are long-term changes which are recognized by the human motor system and allow modifications to maintain the precise biomechanical activities, but overtime the exposure to repetitive physical stress, pain begins as a response to imprecise activities.

8.3.3 Summary

The principle of physiology 'Proximal stability for distal activity' is highly reflected in our contribution through the current study of female and male patients with subacromial impingement syndrome and healthy controls. All patients presented with shoulder pain, weakness, limitation of shoulder movements and functional impairment. Several clinical tests were applied to support the diagnosis as painful-arc, Neer and Hawkin's tests, and others to rule out other pathologies in the shoulder. The confirmation of the diagnosis was achieved either through arthroscopic findings during surgery or as a good response to an impingement-specific physiotherapy programme.

The issues of upper body postural changes and muscle strength deficit had greater implications on female patients than males. The female patients had increased FHP, FSP and greater deficit of shoulder muscle strength; while male patients had increased FSP. Although the male patients' strength was reduced, they were still stronger than healthy female controls. Both postural deviations and deficit in shoulder muscle strength are known predictors to alterations in the scapular position (stability) and coordinated mobility with arm movement at the glenohumeral joint.

In spite that the shoulder range of motion was greater in healthy females than male controls, the female patients lost greater range of motion than males, which can be attributed not only to postural and strength changes but also to psychological effect of pain as 'pain fear or avoidance' and other physical and mental changes reflected by self-reporting questionnaires.

Taking into consideration 'the functional arc' for forward reaching with the combination of flexion/abduction/internal rotation, all patients reflected pain severity, weakness and limitation of motion predominantly within the components of 'the functional arc'.

All aforementioned abnormal findings imposed further changes in stability and function of the shoulder complex. It was obvious that FIT-HaNSA was able to distinguish patients' severity and functional ability from healthy individuals with gradually increased demanding shelving tasks. Furthermore, EMG reflected local muscle activity in functional muscle groups and showed the difference in patients with impingement syndrome.

The combination of EMG and a modification of FIT-HaNSA to assess muscle activation during tasks similar to daily living activities provided a spectrum of activity patterns from low to high demanding tasks.

Both female and male controls demonstrated higher contribution of muscle activity with more demanding tasks in higher levels. The change in activity represented with gradual change in pattern of muscle activity. The scapular positioning, humeral centring and deltoid muscle groups reflected a mirror image pattern in both phases of internal/external rotation tasks. In waist-up and eye-down tasks the muscle groups had increased activity with arm elevation and decreased gradually and smoothly with arm lowering. The scapular muscle group was on top of other muscle groups at the initiation of each phase in the three tasks. The deltoid was the last to contribute its activity with arm elevation and the last to reduce activity with arm lowering. The deltoid's behaviour appeared as 'a time-lag' anticipating a level of contribution by the scapular positioning and humeral head centring muscle groups to be achieved before the deltoid would be able to fire up.

During all tasks, the male patients showed minimal differences in muscle activation pattern from that of controls, which could be attributed to their higher muscle strength, insufficient demanding tasks and probably minimal impairment of proprioceptive sensation due to pain.

The female patients showed obvious differences from controls in all tasks. The muscle groups reflected less contribution with arm elevation tasks and abrupt increase of activity in early stage of arm lowering particularly in eye-down task. This variation was referred to as 'shoulder phenomenon' and attributed to the feeling of insecurity and improper coordination between muscle groups when the loaded arm was exposed to the gravity effect that could be influenced by changes in proprioceptive receptors. Therefore, we emphasize further investigation of the proprioceptive sensation in patients with SIS. As in female controls the scapular positioning muscle group maintained its initial contribution and advanced on top of humeral centring muscle group during arm elevation. In all tasks, the activity of both muscle groups at the start point of phase 1 and end point of phase 2 –reflecting the same time point in the cyclic model - was lower than that of controls and took longer time to reach a level permissible for the contribution of deltoid muscle.

Finally, muscle fatigue assessment during submaximal isometric contraction indicated more fatigue in healthy male than in female volunteers. In general, patients developed less fatigue compared to controls in all tests. This could be explained by pain inhibition or avoidance. In female and male patients, there was less muscle fatigue during isometric submaximal flexion and internal rotation contraction than in controls. In both genders, these movements were challenged by the range of painful arc and changes in scapular position associated with FHP and FSP. Such changes in the scapula included scapular protraction that brings the target point of pain more anteriorly in the range of painful arc; and anterior tilt of the scapula that reduces the subacromial clearance during arm elevation. The SA is more vulnerable to fatigue within the scapular position group during flexion and abduction. The ISP is the highly fatigued muscle in external rotation whereas the SSP is more fatigued during internal rotation.

9 CHAPTER NINE: CONCLUSION & RECOMMENDATIONS

Subacromial impingement syndrome spares neither male nor female, presents as a painful problem in either shoulder regardless of the side of the dominant hand and is observed in all ethnic groups. In this study, a primary difference between patients and controls was scapular management. It was evident that the starting posture and scapular position with subsequent aberrations in scapular movement were critical in the problems associated with subacromial impingement syndrome.

All patients reflected pain severity, weakness and limitation of motion particularly within the components of 'the functional arc'. Forward head and shoulder position produce alterations in scapular position and motion. Scapular protraction, limited upward rotation and anterior tilt bring the target-point of pain further anteriorly and into a lower level within the range of painful arc, leading to predominance of pain, reduced muscle strength and limitation of motion particularly in shoulder flexion, abduction and internal rotation. In addition, the shoulder function of the unaffected side in patients with unilateral SIS is not normal and tends towards changes evident in the shoulder with full SIS.

Generally, the myoelectric manifestations revealed less muscle contribution level and less fatigue in patients than controls; and the changes were more evident in female patients than male patients.

Female patients exhibited greatly reduced muscle strength and more forward head posture and forward shoulder posture than the female controls. Although the muscle strength in male patients was less than male controls but persisted to be stronger than healthy female controls. Males reflected an increase only in their forward shoulder posture. Furthermore, female patients showed greater loss of range of motion than males related to their changes in posture and strength and psychological effects of pain. All these alterations together addressed the function disability and increased severity of subacromial impingement in female patients than males.

EMG was a major tool that reflected local muscle activity in functional muscle groups revealing variations in patients with impingement syndrome. EMG together with modified FIT-HaNSA demonstrated a wide spectrum of muscle activity pattern during low to high demanding tasks.

A higher contribution of muscle activity was evident in demanding tasks of higher levels. The scapular positioning, humeral head centring and deltoid muscle groups reflected a mirror image pattern in both phases of internal/external rotation tasks. In waist-up and eye-down tasks the muscle groups had increased activity with arm elevation but decreased activity with arm lowering. The three tasks were predominantly initiated by the scapular muscle group. The final action during arm elevation and lowering was controlled by the deltoid muscle. In all the three tasks, the male patients reflected minimal differences in the muscle activity patterns compared to their controls , whereas remarkable differences were observed between female patients and controls.

The muscle fatigue assessment indicated less fatigue in patients than controls of both gender particularly in isometric submaximal flexion and internal rotaion contractions where pain inhibition or fear of pain were expected. More fatigue in healthy male than female volunteers emphasized the importance of muscle strength variation. The serratus anterior (SA) is more vulnerable to fatigue within the scapular position group during flexion and abduction. The infraspinatus (ISP) is the highly fatigued muscle in external rotation whereas the supraspinatus (SSP) is more fatigued during internal rotation.

We emphasize the use of combinations of subjective and objective clinical assessments that provide specific and general information about the functioning, disability and health of patients with subacromial impingement syndrome as well as guide the better use of combined clinical tests for better diagnostic accuracy in subacromial impingement. Safe, feasible and reliable tools as those used in the current study will allow proper assessment of posture, muscle strength, range of motion, functional performance and shoulder muscles behaviour and endurance.

The combination of EMG and a modified protocol of FIT-HaNSA provides valuable information on the muscle activity during forward reaching tasks. The overhead consistent activity includes 3 phases rather than 2 phases and requires a different method of analysis and interpretation which is not available in the current study. Further investigation for overhead task is recommended. The use of microphone sensors is time saving and accurate for identifying different phases and synchronizing video recording. We also recommend the use of motion tracking sensors for better interpretation of EMG signals and movements. Last but not least, dynamic muscle fatigue can be evaluated using methods such as 'wavelet' technique.

Finally, physiotherapy protocols which address these problems are likely to be most successful. However, in patients with extreme levels of pain surgery may be the only possibility.

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11 APPENDICES

11.1 Appendix I: An example of the data collection form that includes history taking, physical examination and self-reporting questionnaires.

Checklist

RQ	
Name:	
D.O.B.:	

Date of Investigation:	
Code	
Trust Study No.:	3744

Prior to Patient's Arrival

- ☐ Preparation of testing equipment and cleansing material
- ☐ Preparation of two video cameras and one for standstill photographs
- ☐ Hardware set-up
- ☐ Software set-up
  - ☐ Select appropriate project
  - ☐ Create a new subject
  - ☐ Configure appropriate channels
  - ☐ Cut off frequency 1000Hz
  - ☐ Sampling frequency 3000Hz
  - ☐ Enable video and audio input
  - ☐ Check video correction factor 175ms

Following Patient's Arrival

- ☐ Clarifying any queries
- ☐ Giving brief explanation about the tests
- ☐ Reading and signing the consent form

Clinical Assessment

- ☐ History
- ☐ Questionnaires (Eight)
- ☐ Physical examination
- ☐ Measurement of posture

Shoulder Muscle Strength Testing [Rest for one minute between movement repetitions]

- ☐ Flexors ☐ Abductors ☐ Int. rotators ☐ Ext. rotators

EMG Evaluation [Rest for one minute between the tasks and muscle contractions]

- ☐ Electrodes placement
- ☐ Connect EMG system
- ☐ Manual muscle examination
- ☐ Check the noise level (<10-15 µV)
- ☐ Check baseline offset and shift
- ☐ Recording 15 seconds of resting EMG
- ☐ FIT-HaNSA (short form)
  - ☐ Waist up task (1 min.)
  - ☐ Eye down task (1 min.)
  - ☐ Overhead task (1 min.)
  - ☐ Rotation task (1 min.)
- ☐ Muscle fatigue assessment (at 25% MVC)
  - ☐ Flexors (1 min.)
  - ☐ Abductors (1 min.)
  - ☐ External rotators (1 min.)
  - ☐ Internal rotators (1 min.)

Functional impairment test (Full tests) [Rest for 30 seconds between tasks]

- ☐ Waist Up Task (For 5 minutes)
- ☐ Eyes Down Task (For 5 minutes)
- ☐ Overhead work (For 5 minutes)

HISTORY TAKING

We would appreciate your volunteering some information about you and your shoulder to help us in its evaluation and treatment. Your complete answers to the information below will be helpful; however, you should feel free not to respond to any of the questions that you find objectionable. Please use the back sides of the pages as necessary

Personal Identification:

Your name:	[ ]	**Date of birth:**	[ ]
Address:	[ ]		
Home Phone:	[ ]	**Mobile Phone:**	[ ]
e-mail address:	[ ]		
Occupation:	[ ]	Date last worked:	[ ]
Usual recreation:	[ ]	**Date last done:**	[ ]
Right-handed	[ ]	**Left-handed**	[ ]
Upper limb length:	AP- LE [ ] cm.	LE-RSP:	[ ] cm.
Height	[ ] cm.	**Weight**	[ ] **Kg.**
Affected right shoulder	[ ]	**Affected left shoulder**	[ ]

Present History:

Date your shoulder problem began: [ ]

Describe how your shoulder problem began:

[ ]

Mention five factors that aggravate the pain:

1.
2.
3.
4.
5.

Please describe the nature and progression of functional difficulties:

Please select and detail your experience of any of the following symptoms:

Symptoms	Yes	No	Details
Anterior shoulder pain			
Lateral shoulder pain			
Stiffness			
Weakness			
Night pain			
Rest pain			
Sensation of apparent instability			
Unwanted shifting of the shoulder			

Have you Other Current Medical Problems? Yes No
If yes, please mention the other current medical problems

Are you on treatment plan?

	Yes	Date to start	No
1. Pain killer medication			
2. Acupuncture			
3. Local injection			
4. physiotherapy			
5. Surgery			

Past History

- Please mention any previous health problems you had:
- Previous treatment used

PHYSICAL EXAMINATION

Look (From front, side and back. Compare both sides):

• Shoulder configuration:	
• Atrophy:	
• Asymmetry:	
• Drooped shoulder	
• Prominence or swelling	
• Others	

Feel (Anterior, lateral and posterior bony structures and articulations)
(Rotator cuff, subacromial and subdeltoid bursae, biceps tendon, axilla and other muscles of the shoulder girdle)

• Tenderness:	
• Swelling:	
• Crepitance:	
• Soft tissue defects	
• Prominence or swelling	
• Others	

Move

Type	Side	Flexion	Extension	Abduct.	Adduct.	Ext. Rot.	Int. Rot.
Active	Right						
	Left						
Passive	Right						
	Left						

Clinical Tests

	Clinical Tests	+	-	Details	+	-
Cuff Impingement	Painful arch*					
	Neer's sign*					
	Hawkin's sign*					
	Drop arm*					
	External rotation lag sign*					
	Resisted external rotation*					
	Drop sign*					
	Internal rotation lag sign*					
	Resisted internal rotation*					
	Lift off*					
	full can*					
	Empty can*					
	Napoleon*					
Instability	Load and shift*					
	Anterior drawer					
	Posterior drawer					
	Jahnke					
	Inferior sulcus*					
	Apprehension*					
	Jobe relocation*					
	Surprise / release					
	Leffert					
SLAP Lesion	Anterior slide					
	Crank					
	Slap apprehension					
	O'Brien*					
	Pain provocation*					
	Biceps load 1					
	Biceps load 2					
	Yergasons*					
	Speed's*					

Neck Examination

Muscle Strength Tests

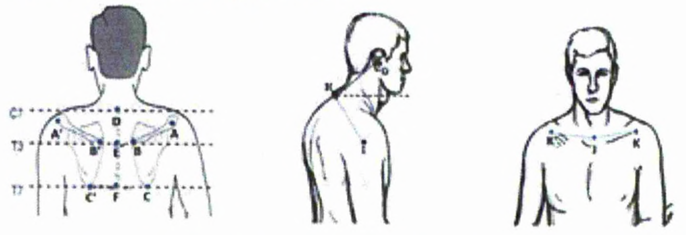
To assess the isometric Maximum Voluntary Contraction (MVC)

- To test the **Shoulder Flexor muscle group:** The armis forward elevatedto 90° in the sagittal plane with the elbow in full extension (at 0°).
- To test the **Shoulder Abductor muscle group:** The armis elevated to 90° in scapular plane:
- To test the **Extrnal rotator muscle group:** The armis close to chest wall and in neutral position with the elbow is flexed to 90° and the forearm in neutral rotation
- To test the **Internal rotator muscle group:** The armis close to chest wall and in neutral position with the elbow is flexed to 90° and the forearm in neutral rotation

Part	Movement	MVC1	MVC2	MVC3	Total	Average	25%*
Right Upper Limb	Flexion						
	Abduction						
	External Rotation						
	Internal Rotation						
Left Upper Limb	Flexion						
	Abduction						
	External Rotation						
	Internal Rotation						

*25% MVC is used for submaximal voluntary contraction to evaluate muscle fatigue on EMG signals

Measurements for upper body posture



Variable	Right side				Left side			
	First	Second	Third	Average	First	Second	Third	Average
AE line length								
AB line length								
AE/AB								
AD line length								
JK line length								
Scapular Index [(JK/AD)x100]								
CF line length with arms at the side of the body								
CF line length with hands at the waist								
CF line length with arms abducted to 90 and internally rotated								
FHP (the angle between GH line and horizontal line)								
FSP (the angle between the horizontal line and HI line)								

Reference points
After palpation, non-allergenic adhesive markers of 6 mm in diameter were attached to the following anatomic points (Figure 1):

1. the posterolateral angle of the acromion (point A)
2. the root of the spine of the scapula (point B)
3. the inferior angle of the scapula (point C)
4. the thoracic spinous process corresponding with the posterolateral angle of the scapula (point D)
5. the thoracic spinous process corresponding with the root of the spine of the scapula (point E)
6. the thoracic spinous process corresponding with the inferior angle of the scapula (point F)
7. the tragus of the ear (point G)
8. the seventh cervical (C7) spinous process to which a 3-cm **straw marker** was attached (point H).
9. the mid-point of the humeral head (point I)
10. the mid-point of the sternal notch (point J)
11. the tip of the coracoid process (point K)

Thoracic Kyphosis

Variable	Measurements			Average
	First	Second	Third	
The depth of the curve (1)				
The height of the curve (2)				
Thorax Kyphosis Index [(1)/(2)]				

Illustration of the Height and Depth of the Thoracic Spine Curve

Functional Impairment Test - Hand and Neck/Shoulder/Arm

(FIT - HaNSA)

Test	Rest	Achieved Duration (seconds)		Score (%)	
		Rt.	Lt.	Rt.	Lt.
"Waist-Up" (for 300 seconds = 100%)	30 seconds				
"Eye-Down" (for 300 seconds = 100%)	30 seconds				
"Overhead Work" (for 300 seconds = 100%)	End				
Total Score = Mean of Test 1, Test 2 and Test 3					

Test Stopping Criteria
Each task can be continued for up to 5 minutes, but is terminated based on the following stopping rules:

1. The subject stops or states it is too painful to continue.
2. The subject is severely off pacing to the extent that they are unable to complete one repetition of the movement within 2 beats of the metronome.
3. The subject substitutes using trunk/whole body movement and cannot correct with feedback for 5 successive repetitions of the task.
4. The examiner believes the subject is at risk of injury or adverse complication if tests were to continue.

QUESTIONNAIRES

(1) OXFORD SHOULDER SCORE

	Date: Treatment Option ☐ Physiotherapy ☐ ASD Examination ☒ Initial ☐ at 3 months ☐ at 6 months ☐ at 12 months

Please put (X) at the most appropriate answer

During the past 4 weeks.........

1. During the past 4 weeks, how would you describe the worst pain you had from your shoulder?
   - ☐ None
   - ☐ Mild
   - ☐ Moderate
   - ☐ Severe
   - ☐ Unbearable

2. Have you had any trouble dressing yourself because of your shoulder?
   - ☐ No trouble at all
   - ☐ Little trouble
   - ☐ Moderate trouble
   - ☐ Extreme difficulty
   - ☐ Impossible to do

3. Have you had any trouble getting in and out of a car or using public transport because of your shoulder?
   - ☐ No trouble at all
   - ☐ Little trouble
   - ☐ Moderate trouble
   - ☐ Extreme difficulty
   - ☐ Impossible to do

4. Have you been able to use a knife and fork at the same time?
   - ☐ No trouble at all
   - ☐ Little trouble
   - ☐ Moderate trouble
   - ☐ Extreme difficulty
   - ☐ Impossible to do

5. Could you do the household shopping on your own?
   - ☐ Yes easily
   - ☐ With little difficulty
   - ☐ With moderate difficulty
   - ☐ With extreme difficulty
   - ☐ No, impossible to do

6. Could you carry a tray containing a plate of food across a room?
   - ☐ Yes easily
   - ☐ With little difficulty
   - ☐ With moderate difficulty
   - ☐ With extreme difficulty
   - ☐ No, impossible to do

(1) OXFORD SHOULDER SCORE

7. Could you brush / comb your hair with the affected arm?

- [ ] Yes easily
- [ ] With little difficulty
- [ ] With moderate difficulty
- [ ] With extreme difficulty
- [ ] No, impossible to do

8. How would you describe the pain you usually had from your shoulder?

- [ ] None
- [ ] Very mild
- [ ] Mild
- [ ] Moderate
- [ ] Severe

9. Could you hang your clothes up in a wardrobe, using the affected arm?

- [ ] Yes easily
- [ ] With little difficulty
- [ ] With moderate difficulty
- [ ] With great difficulty
- [ ] No, impossible to do

10. Have you been able to wash and dry yourself under both arms?

- [ ] Yes easily
- [ ] With little difficulty
- [ ] With moderate difficulty
- [ ] With great difficulty
- [ ] No, impossible to do

11. How much has pain from your shoulder interfered with your usual work (including your house work)?

- [ ] Not at all
- [ ] A little bit
- [ ] Moderately
- [ ] Greatly
- [ ] Totally

12. Have you been troubled by pain from your shoulder in bed at night?

- [ ] No nights
- [ ] Only 1 or 2 nights
- [ ] Some nights
- [ ] Most nights
- [ ] Every night

Total Score:

Notes

(2) CONSTANT-MURLEY SCORE

Code:	Date:
Treatment Option ☐ Physiotherapy ☐ ASD	Examination ☐ Initial ☐ at 3 months ☐ at 6 months ☐ at 12 months

Please mark with a cross

Affected shoulder (resp. Treated shoulder ☐ Right ☐ Left

Your dominant hand ☐ Right ☐ Left

I. **Pain**: Please mark with a cross the average intensity of pain of both shoulders during last week:

Right Shoulder:

No pain ______________________ Severe pain

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Left Shoulder:

No pain ______________________ Severe pain

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

II. **Profession**: Please mark with a cross, for both shoulders, if you have pain or you have been limited using your arm for occupational activity. (If you are not employed, please indicate for main activity of daily living).

	Right Shoulder	Left Shoulder
a. No limitation	☐	☐
b. Less than reduced to the half	☐	☐
c. Reduced to the half	☐	☐
d. More than reduced to the half	☐	☐
e. Completely reduced	☐	☐

III. **Leisure**: Please mark with a cross, for both shoulders, if you have pain or have been limited in recreational activities (Hobby, Sports, Garden, etc.)

	Right Shoulder	Left Shoulder
a. No limitation	☐	☐
b. Less than reduced to the half	☐	☐
c. Reduced to the half	☐	☐
d. More than reduced to the half	☐	☐
e. Completely reduced	☐	☐

(2) CONSTANT-MURLEY SCORE

IV. **Working height**: Please mark with a cross up to which height you are able to perform pain free or without limitation. Activities (i.e. hang up laundry) are able up to and including

	Right Shoulder	Left Shoulder
a. Belt height	☐	☐
b. Chest height	☐	☐
c. Neck height	☐	☐
d. Up to the top of head	☐	☐
e. Above head	☐	☐

V. Sleep: Please mark with a cross, if your sleep is disturbed

	Right Shoulder	Left Shoulder
a. Not disturbed	☐	☐
b. Wake up occasionally	☐	☐
c. Wake up continuously	☐	☐

VI. Pain free forward elevation of the arm

	Right Shoulder	Left Shoulder
a. 0° - 30°	☐	☐
b. 31° - 60°	☐	☐
c. 61° - 90°	☐	☐
d. 91° - 120°	☐	☐
e. 121° - 150°	☐	☐
f. >150°	☐	☐

VII. Pain free lateral elevation of the arm

	Right Shoulder	Left Shoulder
a. 0° - 30°	☐	☐
b. 31° - 60°	☐	☐
c. 61° - 90°	☐	☐
d. 91° - 120°	☐	☐
e. 121° - 150°	☐	☐
f. >150°	☐	☐

(2) CONSTANT-MURLEY SCORE

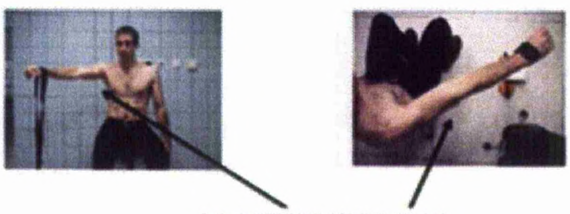
VIII. Pain free internal rotation behind the body, the hand is......

	Right Shoulder	Left Shoulder
a. at the side of the body	☐	☐
b. Up to the origin of the pocket	☐	☐
c. Up to under the belt	☐	☐
d. At the belt level	☐	☐
e. Just above the belt	☐	☐
f. Between the scapulae	☐	☐

IX. Pain free external rotation, the hand is........

	Right Shoulder	Left Shoulder
a. at the neck with elbow held forward	☐	☐
b. on top of the head with elbow held forward	☐	☐
c. at the neck with elbow held back	☐	☐
d. on top of the head with elbow held back	☐	☐
e. above head	☐	☐
f. No painful movement	☐	☐

X. Measurement of power: Please fill a paper-bag with 1L Tetra-Packs and keep this in the below-mentioned position for 5 seconds. Please indicate how much kg you are able to keep.



Arm positioned in 90° abduction to the body and slightly infront of the body

Right: **left:**

weight: ____ **kg =** **lbs** **weight:** ____ **kg =**

Notes:

THANK YOU!

(3) DISABILITIES OF THE ARM SHOULDER AND HAND

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

Item	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	Unable
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g. wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed	1	2	3	4	5
10.Carry a shopping bag or briefcase	1	2	3	4	5
11.Carry a heavy object (over 10 lbs).	1	2	3	4	5
12.Change a light bulb overhead.	1	2	3	4	5
13.Wash or blow dries your hair.	1	2	3	4	5
14.Wash your back.	1	2	3	4	5
15.Put on a pullover sweater.	1	2	3	4	5
16.Use a knife to cut food.	1	2	3	4	5
17.Recreational activities which require a little effort (e.g. card playing, knitting, etc.)	1	2	3	4	5
18.Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19.Recreational activities in which you move your arm freely (e.g., playing Frisbee, badminton, etc.).	1	2	3	4	5
20.Manage transportation needs (getting from one place to another).	1	2	3	4	5
21.Sexual activities	1	2	3	4	5

(3) DISABILITIES OF THE ARM SHOULDER AND HAND

Item	Not at all	Slightly	Moderately	Quite a bit	Extremely
22. *During the past week, to what extent* has your arm, shoulder or head problem interfered with your normal social activities with family, friends, neighbours or groups? (*circle number*).	1	2	3	4	5

	Not limited at all	Slightly limited	Moderate	Very limited	Unable
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? (*circle number*).	1	2	3	4	5

Please rate the severity of the following symptoms in the last week (*circle number*).

Item	None	Mild	Moderate	Severe	Extreme
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

Item	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	So much difficulty that I can't sleep
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (*circle number*)	1	2	3	4	5

(3) DISABILITIES OF THE ARM SHOULDER AND HAND

Item	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. (*circle number*)	1	2	3	4	5

DASH DISABILITY/SYMPTOMS SCORE = $\left[\frac{(sum\ of\ responses)}{n} - 1\right] \times 25,$

Where n is equal to the number of completed responses.
A DASH score may <u>not</u> be calculated if there are greater than 3 missing items.

WORK MODULE (OPTIONAL)
The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).
Please indicate what your job/work is:

- I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty?

Item	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	Unable
1. Using your usual technique for your work?	1	2	3	4	5
2. Doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. Doing your work as well as you would like?	1	2	3	4	5
4. Spending your usual amount of time doing your work?	1	2	3	4	5

(3) DISABILITIES OF THE ARM SHOULDER AND HAND

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)
The following questions relate to the impact of your arm, shoulder or hand problem on playing your *musical instrument or sport or bath*.
If you play more than one sport or instrument (or play both), please answer with respect to the activity which is most important to you

- **I do not play a sport or an instrument. (You may skip this section.)**

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty?

Item	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	UNABLE
1. Using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. Playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. Playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. Spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.

An optional module score may <u>not</u> be calculated if there are any missing items

(4) LIFESTYLE

Date:
Treatment Option
☐ Physiotherapy ☐ ASD
Examination
☒ Initial ☐ at 3 months
☐ at 6 months ☐ at 12 months

What is **the physical demand** and amount of **overhead activity** involved in your job, now or in the past?

Grade	Physical demand *(Pl. Tick)* Current	Physical demand *(Pl. Tick)* Past	Overhead activity *(Pl. Tick)* Current	Overhead activity *(Pl. Tick)* Past
Light	☐	☐	☐	☐
Medium	☐	☐	☐	☐
Moderately heavy	☐	☐	☐	☐
Heavy	☐	☐	☐	☐
Very heavy	☐	☐	☐	☐

How much **stress** do and did you feel at work?

Work Stress	Current	Past
Often	☐	☐
Sometimes	☐	☐
Seldom	☐	☐
Never	☐	☐

How **satisfied** are and were you with your job? (Pl. Tick)

	Current	Past
Not satisfied	☐	☐
Somewhat	☐	☐
Mostly	☐	☐
Totally satisfied	☐	☐

Smoking Habit?
Never smoked ☐ Former smoker ☐ Current smoker ☐

No of cigarettes smoked per day?
Less than 10 ☐ 10 - 20 ☐ more than 20 ☐

For how many years have you smoked?...........
If a former smoker, which year did you stop?...

(4) LIFESTYLE

Alcohol consumption habit?

Never consumed ☐ Former consumer ☐ Current consumer ☐

Beer (No. Of pints consumed per week)............................	
Wine (No. Of glasses consumed per week)......................	
Spirits of equivalent (No. Of 30 ml measures/week)........	
No of years of alcohol consumption..................................	
If a former consumer, which year did you stop................	

Coffee (caffeine) Consumption habit?

Never consumed ☐ Former consumer ☐ Current consumer ☐

No. Of cups consumed per day...	
No. Of years of consumption...	
If a former consumer, which year did you stop?................	

(5) General Health (SF12)

Please put a cross (X) at the most appropriate response for each question.

1. In general, would you say your health is ...
   - ☐ Excellent (1)
   - ☐ Very good (2)
   - ☐ Good (3)
   - ☐ Fair (4)
   - ☐ Poor (5)

   The following two questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

2. Moderate Activities, such as moving a table, pushing a vacuum cleaner, bowling or playing golf:
   - ☐ Not at all (1)
   - ☐ A little (2)
   - ☐ A lot (3)

3. Climbing several flights of stairs:
   - ☐ Not at all (1)
   - ☐ A little (2)
   - ☐ A lot (3)

   During the PAST 4 WEEKS, how much of the time have you had any of the following problems with your work or regular daily activities As a result of your physical health?

4. Accomplished less than you would like:
   - ☐ None of the time (1)
   - ☐ A little of the time (2)
   - ☐ Some of the time (3)
   - ☐ Most of the time (4)
   - ☐ All of the time (5)

5. You were limited in the kind of work or other activities you could do:
   - ☐ None of the time (1)
   - ☐ A little of the time (2)
   - ☐ Some of the time (3)
   - ☐ Most of the time (4)
   - ☐ All of the time (5)

6. During the PAST 4 WEEKS, how much did pain interfere with your normal work (including both outside the home and housework)?
   - ☐ Not at all (1)
   - ☐ A little bit (2)
   - ☐ Moderately (3)
   - ☐ Quite a bit (4)
   - ☐ Extremely (5)

(5) General Health (SF12)

7. During the past 4 weeks, how much of the time have you a lot of energy?
   - ☐ All of the time (1)
   - ☐ Most of the time (2)
   - ☐ Some of the time (3)
   - ☐ A little of the time (4)
   - ☐ None of the time (5)

During the past 4 weeks, how much of the time have you had any of the following problems with your work or other daily activities as a result of any emotional problems, such as feeling depressed or anxious?

8. Accomplished less than you would like:
   - ☐ None of the time (1)
   - ☐ A little of the time (2)
   - ☐ Some of the time (3)
   - ☐ Most of the time (4)
   - ☐ All of the time (5)

9. You have trouble doing work or other activities as carefully as usual:
   - ☐ None of the time (1)
   - ☐ A little of the time (2)
   - ☐ Some of the time (3)
   - ☐ Most of the time (4)
   - ☐ All of the time (5)

10. During the past 4 weeks, how much of the time have you felt calm and peaceful?
    - ☐ All of the time (1)
    - ☐ Most of the time (2)
    - ☐ Some of the time (3)
    - ☐ A little of the time (4)
    - ☐ None of the time (5)

11. During the past 4 weeks, how much of the time have you felt down hearted and blue?
    - ☐ None of the time (1)
    - ☐ A little of the time (2)
    - ☐ Some of the time (3)
    - ☐ Most of the time (4)
    - ☐ All of the time (5)

12. During the last 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities, like visiting with friends, relatives, etc.
    - ☐ None of the time (1)
    - ☐ A little of the time (2)
    - ☐ Some of the time (3)
    - ☐ Most of the time (4)
    - ☐ All of the time (5)

(6) UPPER LIMB FUNCTIONAL INDEX

Your upper limb (arm) may make it difficult to do some of the things you normally do. This list contains sentences people often use to describe themselves when they have such problems. Think of yourself over the last few days. If an item describes you, mark the box with a cross (X). If not, leave the box blank.

Due to my arm:

☐ 1. I stay at home most of the time.

☐ 2. I change position frequently for comfort.

☐ 3. I avoid heavy jobs (e.g. cleaning, lifting more than 5kg or 10 lbs and gardening).

☐ 4. I rest more often.

☐ 5. I get others to do things for me.

☐ 6. I have pain almost all the time.

☐ 7. I have difficulty lifting and carrying (e.g. bags and shopping up to 5kg or 10 lbs.

☐ 8. My appetite is now different.

☐ 9. My walking or normal recreational activity is affected.

☐ 10. I have difficulty with normal home or family duties and chores.

☐ 11. I sleep less well.

☐ 12. I need assistance with personal care (e.g. washing and hygiene).

☐ 13. My regular daily activities (e.g. work and social contact) are affected.

☐ 14. I am more irritable and / or bad tempered.

☐ 15. I feel weak and / or stiffer

(6) UPPER LIMB FUNCTIONAL INDEX

☐ 16. My transport independence is affected (driving, public transport)

☐ 17. I have difficulty putting my arm into a shirt sleeves or need assistance dressing.

☐ 18. I have difficultly writing or using a key board and / or "mouse".

☐ 19. I am unable to do things at or above shoulder height

☐ 20. I have difficulty eating or using utensils (e.g. knife, fork, spoon, chop sticks)

☐ 21. I have difficulty holding and moving dense objects (e.g. mugs, jars and cans).

☐ 22. I tend to drop things and / or have minor accidents more frequently.

☐ 23. I use the other arm more often

☐ 24. I have difficulty with buttons, keys coins, taps/ faucets, containers or screw top lids.

☐ 25. I have difficulty opening, holding pushing or pressing (e.g. triggers, lever and heavy doors).

Patient Specific Index

Note 5 activities that are important to you and affected by your arm problem. If you cannot think of 5, choose from the ones you have marked above. Score each activity on a scale range as follows, you may use half marks.

	Activity	Score
1		
2		
3		
4		
5		

Think of yourself over the last few days and due to your arm – assess your overall status compared to your normal pre-injury level?

0	1	2	3	4	5	6	7	8	9	10
Pre-injury or Normal										Worst Possible

(7) HOSPITAL ANXIETY AND DEPRESSION SCALE

Please circle the most appropriate response for each question.

	Questions	Yes definitely	Yes sometimes	No, not much	No, not at all
1	I wake early and then sleep badly for the rest of the night.	3	2	1	0
2	I get very frightened or get panic feelings for apparently no reason at all.	3	2	1	0
3	I feel miserable and sad.	3	2	1	0
4	I feel anxious when I go out of the house on my own.	3	2	1	0
5	I have lost interest in things.	3	2	1	0
6	I get palpitations or sensations of "butterflies" in my stomach or chest.	3	2	1	0
7	I have a good appetite.	0	1	2	3
8	I feel scared or frightened.	3	2	1	0
9	I feel life is not worth living.	3	2	1	0
10	I still enjoy the things I used to.	0	1	2	3
11	I am restless and I can't keep still.	3	2	1	0
12	I am more irritable than usual.	3	2	1	0
13	I feel as though I have slowed down.	3	2	1	0
14	Worrying thoughts constantly go through my mind	3	2	1	0

(8) THE McGILL PAIN QUESTIONNAIRE

There are 3 parts of this questionnaire

Part 1: What Does Your Pain Feel Like?

Statement: Some of the following words below describe your present pain. Circle ONLY those words that best describe it. Leave out any category that is not suitable. Use only a single word in each appropriate group – the one that applies best.

Group	Descriptor	Point
(1) SENSORY Temporal	Flickering	1
	Quivering	2
	Pulsing	3
	Throbbing	4
	Beating	5
	Pounding	6
(2) SENSORY Spatial	Jumping	1
	Flashing	2
	Shooting	3
(3) SENSORY Punctuate Pressure	Pricking	1
	Boring	2
	Drilling	3
	Stabbing	4
	Lancinating	5
(4) SENSORY Incisive Pressure	Sharp	1
	Cutting	2
	Lacerating	3
(5) SENSORY Constrictive Pressure	Pinching	1
	Pressing	2
	Gnawing	3
	Cramping	4
	Crushing	5
(6) SENSORY Traction Pressure	Tugging	1
	Pulling	2
	Wrenching	3
(7) SENSORY Thermal	Hot	1
	Burning	2
	Scalding	3
	Searing	4
(8) SENSORY Brightness	Tingling	1
	Itchy	2
	Smarting	3
	Stinging	4

Group	Descriptor	Point
(9) SENSORY Dullness	Dull	1
	Sore	2
	Hurting	3
	Aching	4
	Heavy	5
(10) SENSORY	Tender	1
	Taut	2
	Rasping	3
	Splitting	4
(11) AFFECTIVE Tension	Tiring	1
	Exhausting	2
(12) AFFECTIVE Autonomic	Sickening	1
	Suffocating	2
(13) AFFECTIVE Fear	Fearful	1
	Frightening	2
	Terrifying	3
(14) AFFECTIVE Punishment	Punishing	1
	Gruelling	2
	Cruel	3
	Vicious	4
	Killing	5
(15) AFFECTIVE	Wretched	1
	Blinding	2
(16) EVALUATIVE	Annoying	1
	Troublesome	2
	Miserable	3
	Intense	4
	Unbearable	5
(17) MISCELLA-NEOUS	Spreading	1
	Radiating	2
	Penetrating	3
	Piercing	4

(8) THE McGILL PAIN QUESTIONNAIRE

(18) MISCELLA-NEOUS	Tight	1
	Numb	2
	Drawing	3
	Squeezing	4
	Tearing	5

(19) MISCELLA-NEOUS	Cool	1
	Cold	2
	Freezing	3
(20) MISCELLA-NEOUS	Nagging	1
	Nauseating	2
	Agonising	3
	Dreadful	4
	Torturing	5

Part 2: How does your pain change with Time?

Question	Response	Points
Which word or words would you use to describe the pattern of your pain?	Continuous, steady, constant	1
	Rhythmic, periodic, intermittent	2
	Brief, momentary, transient	3

<u>Do the following items increase or decrease your pain?</u>

What kinds of things decrease your pain?

(1) --
(2) --
(3) --
(4) --
(5) --

What kinds of things increase your pain?

(1) --
(2) --
(3) --
(4) --
(5) --

(8) THE McGILL PAIN QUESTIONNAIRE

PART 3: How strong is your pain?

Statement: People agree that the following 5 words (mild, discomforting, distressing, horrible, excruciating) represent pain of increasing intensity. To answer each question below circle the most appropriate response.

Question	Response	Points
Which word best describes your pain right now?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5
Which word describes it at its worst?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5
Which word describes it when it is at its least?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5
Which word describes the worst toothache you have ever had?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5
Which word describes the worst headache you have ever had?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5
Which word describes the worst stomach ache you have ever had?	Mild	1
	Discomforting	2
	Distressing	3
	Horrible	4
	Excruciating	5

Radiological Assessment

Antero-Posterior View	Yes	No	Details
OA changes			
Greater tuberosity sclerosis			
Greater tuberosity cyst			
Osteopenia			
Calcific deposit			
Hill-sachs lesion			
Reverse Hill –Sachs lesion			
Bony Bankart			
Others			

Axial View	Yes	No	Details
OA changes			
Greater tuberosity sclerosis			
Greater tuberosity cyst			
Osteopenia			
Calcific deposit			
Hill-sachs lesion			
Reverse Hill –Sachs lesion			
Bony Bankart			
Others			

Supraspinatus Outlet View	Yes	No	
Acromion Type (I)			
Acromion Type (II)			
Acromion Type (III)			
Spur under the acromion			
Acromioclavicular joint OA			
Others			

11.2 Appendix II: A summary of the demographic data associated with all participants in the study.

11.2.1 Appendix II: Table 1: A summary of the demographic data associated with all participants in the study.

The gender of participants is indicated by (F) for females and (M) for males. The participants were classified according to their country of origin into Caucasian (C) and non-Caucasian (NC).The pathology of patients was categorized into unilateral impingement (UIMP), unilateral impingement improved (UIMPIMP), bilateral impingement (BIMP), and unilateral impingement with another associated pathology including superior labrum from anterior to posterior (SLAP) lesion, rotator cuff partial tear (RCPT), rupture of long head of biceps brachii (RLHBB) and tendinosis of long head of biceps brahii (TLHBB). A prefix of R (right) or L (left) was added to the pathology category to specify the affected shoulder in UIMP patients. NA indicates no abnormality detected. The pain duration is indicated in months.

No.	Participant code	Patient/ control	Age (years)	Height (cm)	Weight (kg)	Gender	Country of origin	Ethnicity	Handedness	Pathology	Pain duration (months)
1	P1CB500485	patient	55	167	118	F	UK	C	Right	R-UIMP	7
2	P2EP412107	patient	63	158	95	F	UK	C	Right	L-UIMP	18
3	P3JM412929	patient	60	174	90	F	UK	C	Right	R-UIMPIMP	14
4	P4EW500897	patient	53	185	96	M	UK	C	Right	L-UIMP	12
5	P5PT401838	patient	62	155	64	F	UK	C	Left	L-UIMPIMP	12
6	P6BS500006	patient	54	160	103	F	UK	C	Right	R-UIMP	18
7	P7WR702377	patient	33	152	58	M	Pakistan	NC	Right	BIMP	14
8	P8JB501472	patient	58	164	74	M	UK	C	Right	BIMP	24
9	P9KL400186	patient	64	158	70	F	UK	C	Right	L-UIMP	9
10	P10LD501224	patient	56	170	89	F	UK	C	Right	BIMP	12
11	P11MA600731	patient	49	173	63	F	UK	C	Right	BIMP	18
12	P12GS500438	patient	52	160	75	F	Nigeria	NC	Right	R-UIMPIMP	24
13	P13EB402756	patient	64	180	84	M	UK	C	Right	R-UIMP+SLAP	24
14	P14AC511926	patient	54	179	88	M	UK	C	Right	BIMP	18
15	P15SC602647	patient	43	177	83	M	UK	C	Right	L-UIMP	15
16	P16CS512025	patient	55	186	86	M	UK	C	Right	L-UIMP	16
17	P17MW510117	patient	53	163	69	F	UK	C	Right	R-UIMPIMP	24
18	P18JA500832	patient	55	180	99	M	UK	C	Right	L-UIMP+RCPT	12
19	P19GB511310	patient	60	170	80	M	UK	C	Left	L-UIMP+RLHBB	21
20	P20PR601645	patient	54	152	64	F	UK	C	Right	BIMP	8
21	P21RW512215	patient	55	164	73	M	UK	C	Right	BIMP	8
22	P22AW611024	patient	46	168	83	F	UK	C	Right	L-UIMP	11
23	P23AP502938	patient	52	155	55	F	UK	C	Right	L-UIMP	6
24	P24PY400149	patient	61	174	94	M	UK	C	Right	BIMP	20
25	P25PL502339	patient	51	178	82	M	UK	C	Right	R-UIMP+SLAP	18
26	P26GB502465	patient	55	165	67	F	UK	C	Right	L-UIMP	30
27	P27MB311628	patient	72	180	83	M	UK	C	Right	L-UIMP	24
28	P28PD411427	patient	63	152	72	F	UK	C	Right	L-UIMP	15
29	P29PB500358	patient	52	155	70	F	UK	C	Right	L-UIMP	9
30	P30PW500697	patient	53	158	66	F	UK	C	Right	BIMP	14
31	P31NW411929	patient	61	152	76	F	UK	C	Right	R-UIMP	8
32	P32JT500896	patient	54	177	89	M	UK	C	Right	R-UIMP+RCPT	11
33	P33MS602113	patient	48	155	77	M	UK	C	Right	BIMP	7
34	P34GS502899	patient	51	174	87	M	UK	C	Right	R-UIMP	8

Continued from appendix II: Table 1.

No.	Participant code	Patient/ control	Age	Height (cm)	Weight (kg)	Gender	Country of origin	Ethnicity	Handedness	Pathology	Pain duration (months)
35	P35MG501061	patient	59	183	90	M	UK	C	Right	R-UIMP	12
36	P36RN500472	patient	58	162	82	F	UK	C	Right	BIMP	8
37	P37KV600670	patient	50	180	105	M	UK	C	Right	BIMP	10
38	P38CT600972	patient	48	170	90	F	UK	C	Right	L-UIMP	14
39	P39AA512006	patient	54	165	61	M	UK	C	Right	R-UIMP+TLHBB	19
40	C01VA512018	control	52	158	62	F	UK	C	Right	NA	-
41	C02AR602176	control	44	177	68	M	UK	C	Right	NA	-
42	C03IW600722	control	48	170	72	M	UK	C	Right	NA	-
43	C04SR800762	control	28	164	65	F	India	NC	Right	NA	-
44	C05JD712417	control	33	186	80	M	UK	C	Right	NA	-
45	C06RH712512	control	38	191	120	M	UK	C	Right	NA	-
46	C07JS503117	control	53	163	62	F	UK	C	Right	NA	-
47	C08AA602398	control	42	186	71	M	Sudan	NC	Right	NA	-
48	C09EA600115	control	45	156	70	M	Sudan	NC	Right	NA	-
49	C10AB502146	control	54	158	70	M	Yemen	NC	Right	NA	-
50	C11SE501270	control	60	175	78	M	Sudan	NC	Left	NA	-
51	C12HS401522	control	68	178	97	M	India	NC	Right	NA	-
52	C13YA801072	control	28	166	72	M	Iraq	NC	Right	NA	-
53	C14AA611006	control	44	168	74	M	Yemen	NC	Right	NA	-
54	C15AK500115	control	36	174	74	M	Egypt	NC	Right	NA	-
55	C16AA710104	control	55	167	85	M	Yemen	NC	Right	NA	-
56	C17IA503075	control	55	166	70	M	Palestine	NC	Right	NA	-
57	C18JS603069	control	41	168	68	M	Yemen	NC	Right	NA	-
58	C19MS600898	control	42	175	68	M	Morocco	NC	Right	NA	-
59	C20HN600544	control	46	156	62	M	Yemen	NC	Left	NA	-
60	C21MM703053	control	38	175	78	F	UK	C	Right	NA	-
61	C22SR601987	control	44	170	68	F	UK	C	Right	NA	-
62	C23TC412015	control	66	188	84	M	UK	C	Right	NA	-
63	C24JW600382	control	49	178	74	F	UK	C	Right	NA	-
64	C25SA700621	control	40	166	68	F	UK	C	Right	NA	-
65	C26MR501157	control	54	168	80	F	UK	C	Right	NA	-
66	C27NU700467	control	34	163	50	F	UK	C	Right	NA	-
67	C28KL500648	control	53	168	70	M	UK	C	Right	NA	-
68	C29BS502372	control	54	162	72	F	UK	C	Right	NA	-
69	C30CU508246	control	55	170	84	M	UK	C	Right	NA	-
70	C31CC802610	control	31	173	69	F	UK	C	Right	NA	-
71	C32LM702257	control	34	168	69	F	UK	C	Right	NA	-
72	C33EO603035	control	46	178	76	M	UK	C	Right	NA	-
73	C34IM600894	control	47	182	82	F	UK	C	Right	NA	-

11.3 Appendix III: Clinical tests available for the assessment of shoulder disorders.

Neer sign[81]**:** The sign is assessed with the patient standing. The scapula is stabilized by the examiner, and the arm is forward flexed until the patient reports pain or full elevation is reached.
Hawkins and Kenndy sign[245]**:** The patient is examined in sitting position with their arm and elbow flexed to 90°, supported by the examiner to ensure maximal relaxation. The examiner stabilises the arm proximal to the elbow with one hand and with the other holds just proximal to the patient's wrist. The arm is forced into internal rotation. Pain is located to the subacromial space due to impingement of the rotator cuff between the greater tuberosity and undersurface of acromion.
Drop Arm: The examiner passively abducts the patient's shoulder to 90° in the coronal plane. The patient is asked to sustain this position while the examiner "pushes" the patient's arm downwards near their elbow. If the arm drops, that indicates a full thickness rotator cuff tear.
External rotation Lag Sign[255]**:** The patient is examined in sitting position with their back to the examiner. Their elbow is passively flexed to 90° and shoulder held at 20° in the scapula plane near maximal external rotation (i.e. maximum external rotation minus 5° to avoid elastic recoil in the shoulder. The patient is asked to actively maintain the external rotation position as the examiner releases the wrist while maintaining limb support at the elbow. The test is positive if a lag or angular drop occurs due to infraspinatus muscle tear. The magnitude of the lag is recorded to the nearest 5°.
Full Cans[256]**:** The patient is tested at 90° elevation in the scapula plane and 45° external rotation (full can). Patient resists downward pressure exerted by the examiner at patient's elbow or wrist. Pain is localized to subacromial region with or without weakness.
Empty Cans[211]**:** The patient is tested at 90° elevation in the scapula plane and full internal rotation (empty can) or 45° external rotation (full can). Patient resists downward pressure exerted by the examiner at patient's elbow or wrist.
Internal Rotation Resistance Test[258]**:** The patient's arm is held in 90° abduction in the coronal plane and approximately 80° of external rotation. The patient is first asked to perform resisted external rotation against the examiner's hand followed by internal rotation. Good strength of the external rotators and apparent weakness in internal rotation is a positive test.
Lift-Off[259]**:** The patient is examined in a standing position and asked to place their hand behind their back with the dorsum of the hand resting in the mid-lumbar spine region. The dorsum of the hand is raised off the back by maintaining or increasing internal rotation of the humerus and extension at the shoulder. To perform this test, the patient must have full passive internal rotation so that it is physically possible to place the arm in the desired position and pain cannot be a limiting factor during the maneuver. The ability to actively lift the dorsum of the hand off the back constitutes a normal lift-off test and indicates subscapularis rupture or dysfunction.
Belly-press (Napoleon)[260]**:** The patient is asked to maintain the following position. Both hands press on the abdomen, while the elbow and forearm are placed in the frontal plane. The sign is positive if the patient is unable to maintain the elbow in the given position. When there is a tear in the subscapularis, the elbow typically drops or lags posteriorly.
Load and Shift[261]**:** The examiner creates a loading force to relocate the humeral head centrally in the glenoid. In this "loaded position" directional stresses are applied. The examiner places one hand over the shoulder and scapula to stabilise the shoulder girdle and uses the other hand to grasp the humeral head. The humerus is loaded into the glenoid and then translated anteriorly and posteriorly. As the applied stress is increased, the humeral head may be felt to ride up the glenoid rim. This test does not only assess the amount of translation but also provides an idea about the adequacy of the glenoid lip. It is critically important to compare the two shoulders to appreciate similarities or differences in translation. The test is then repeated in supine position. In this position, the arm is grasped and positioned in about 29° of abduction and forward flexion.

The humeral head is again loaded and then posterior and anterior stresses are applied. Although the translation is assessed initially in the neutral position with the arm by the side, it is important to assess translation in other positions as well. For example, by progressively externally rotating the arm in the normal shoulder in abduction, one should appreciate less translation anteriorly as the inferior glenohumeral ligament (GHL) becomes tight and acts as a restrain. Similarly, by internally rotating the arm, posterior translation is diminished with an intact posterior capsular structure. Grading system is utilised to quantify the amount of translation: (1) Mild 0-1 cm translation, (2) Moderate >1-2 cm translation or translate to glenoid, and (3) Severe >2 cm translation or over the rim.
Anterior-Drawer[262]: Ideally this test should be performed with the patient in supine as sitting and standing positions have been shown to be unreliable with respect to reproducibility. The examiner stands facing the affected shoulder e.g. left. They fix the patient's left hand in their right axilla by adducting their humerus. The affected shoulder is held at 80°-120° of abduction, 0°-20° of forward flexion and 0°-30° of external rotation. The examiner holds the patient's scapula spine forward with his index and middle fingers; his thumb exerts counter pressure on the coracoids. The scapula is fixed. The examiner uses his right hand to grasp the patient's relaxed upper arm and draw it anteriorly with a force comparable to that used in a Lachmann's test. (NB it is possible to repeat the anterior drawer in different positions of abduction and external rotation as described in the load and shift test to test the individual components of the GHL complex). The relative movement between the fixed scapula and the movable humerus can easily be appreciated and graded. Occasionally the examiner may reproduce an audible click on forward movement of the humeral head due to labral pathology and this is usually associated with apprehension.
Posterior-Drawer[262]: The patient must be examined in supine position. The examiner stands level with the affected shoulder. Assuming the left shoulder is being tested, the examiner grasps patient's proximal forearm with his left hand, flexes elbow to about 120°, and positions shoulder into 80°-120° of abduction and 20°-30° of forward flexion. The examiner holds the scapula using his right hand with index and middle finger on the scapula spine and thumb lies immediately lateral to the coracoids process; so that its ulnar aspect remains in contact with the coracoids whilst performing the test. With his left hand, the examiner slightly rotates the upper arm medially and flexes it to about 90°. During this manoeuvre, the thumb of the examiner's right hand induces sublaxation of the humeral head posteriorly. This posterior displacement can be appreciated as the thumb slides along the lateral aspect of coracoids process towards the glenoid, and the humeral head abuts against the ring finger of examiner's right hand. This manoeuvre is pain free, but is often associated with a slight to moderate degree of apprehension. As in the load and shift and anterior-drawer tests, this can be repeated in different positions of flexion and medial rotation to search out the posterior GHL complex and posterior labral integrity.
Jahnke: Reproduces posterior subluxation by posteriorly stressing the forward flexed arm at 90° of elevation in neutral rotation. Continued stress whilst extending the arm into an abducted position will produce a clunk or obvious feeling of reduction of a subluxed humeral head. The patient often appreciates this as a reproduction of their instability.
Inferior-Sulcus[263]: The patient is examined in a sitting or standing position with the shoulder in a neutral position. It is important for the shoulder muscles to be relaxed with stress applied above the elbow (this eliminates the effect of biceps and triceps brachii). Traction is applied with the arm grasped downward. The examiner watches for dimpling of the skin below the acromion. Palpation reveals widening of the subacromial space between the acromion and the humeral head.
Apprehension[170]: In supine, the patient is positioned with the scapula supported by edge of the examining table. The arm is positioned in 90° abduction and external rotation. With increasing external rotation the examiner watches for apprehension of the patient. This test is often performed in sitting position and the examiner exerts an anterior translator force with their thumb placed posteriorly on the humerus. However, their fingers are anterior to control any sudden instability episode that may occur.
Jobe Relocation[170]: The examiner repeats the apprehension test as described above and notes the amount of external rotation before the onset of apprehension. The examiner then returns to the start position and applies a posterior stress over the humeral head. Finally, the examiner then repeats the external rotation manoeuvre and again notes the mount of external rotation as onset of apprehension.

11.4 Appendix IV: An example of an individual summary sheet of non-electromyography data.

Patient Details	P15SC602647
Age	43
gender	Male
Height (Cm)	177
Weight (Kg)	83
Occupation	Electrician
Recreation	Cycling
Recruitement	Surgery
Date of assessment	08/03/10
BMI	26

Shoulder Details	
Dominant hand	R
Affected hand	L*
Side for EMG	L
Onset of pain	15 months
Presentation to G.P.	12 months
Precipitating factor/s	Pulling cables/posts
On Treatment	Yes

Shoulder Symptoms	
Pain Location	Lateral to acromion
Pain Character	Dull ache
Pain at night	Some nights
Pain at rest	N
Stiffness	Moderate
Weakness	Mild
Tingling	N
Feel instability	N

Other Curt Med Probs & TTT
N
N
N

Shoulder Treatment	
Painkiller	N
Acupuncture	N
Local infiltration	Once in Dec.. 2009
Physiotherapy	N
Surgery	Planned

Past Med Probs
Rt shoulder impingement (2003)
N

Past Med Treatment
Local infiltration+physio
N

Clinical Examination

Look and Feel	Unaffec. (R)	Affec. (L)
Assymetry	Contour change	N
Atrophy	Deltoid	N
deltoid (D), Suprasp (S), Infrasp (IS) Trapezius (T)	Ss + Is	N
Tendernes	N	Lateral to acr.
	N	N
Muscle spasm	N	N
Swelling	N	N
Crepitation	N	N

Motion & Posture		Unaffec. (R)	Affec. (L)
Range of motion	Flexion	180	180
	Extension	50	50
	Abduction	180	180
	Horiz. Add.	40	40
	Ext. Rotation	60	65
	Int. Rotation	T12	ISP
Posture	AE (cm)	21.6	21.3
	AB (cm)	15.6	14.8
	JK (cm)	15.5	16.5
	AD (cm)	20.0	20.0
LSS test arms at side		8.4	8.1
LSS test at 90 abd.		10.5	9.3

Clinical Tests	Unaffec. (R)	Affec. (L)
Painful arc	Discomfort laterally at 160	Discomfort laterally at 160
Neer's sign	N	N
Hawkin's sign	N	N
Drop arm	N	N
Ext. Rot. Lag sign	N	N
Ext. Rot. Resistance	N	N
Drop sign	N	N
Intl. Rot. Lag sign	N	N
Int. Rot. Resist.	N	N
Lift off	N	N
full can	N	N
Empty can	N	N
Belly-Press	N	N
Load and shift	N	N
Inferior sulcus	N	N
Apprehension	N	N
Jobe rlocation	N	N
O'Brien	N	Deep posterior pain
Pain provocation	N	N
Yergasons	N	N
Speed's	N	N

Muscle Strength (Newton Unit)	Unaffec. (R)	Affec. (L)
Flexors	118	112
Abductors	117	107
Ext. rotators	151	134
Int. rotators	261	242

FIT-HaNSA completed	
Tested Shoulder (L)	
	%
Waist-up	100
Eye-down	60
OH work	59
Average	73

Questionnaires		Unaffec. (R)	Affec.(L)	Range
	OSS		39	0-48
	CMS	100	87	0-100
DASH	D/S Score		13	0-100
	Work (Opt.)		38	0-100
	Sport (Opt.)		0	0-100
	ULFI		16	0-100
	PSI		0	0-100
MPQ	PRI		9	1-78
	NWC		3	1-3
	PPI		18	1-30
HADS	Anxiety			0-21
	Depression			0-21
	Total		5	0-42

Health SF12	
	Range
19	12-60
Lifestyle	

11.5 Appendix V: The functional impairment test-head, and neck/shoulder/arm protocol (taken from 'Additional File 1: *The FIT-HaNSA Protocol'* provided with[58])

The link: [http://www.biomedcentral.com/content/supplementary/1471-2474-8-42-S1.doc]

The Functional Impairment Test-Head, and Neck/Shoulder/Arm (FIT-HaNSA) Protocol

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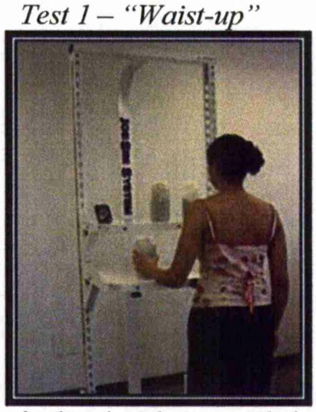
Test Purpose: To provide a brief measure of functional performance of the upper limb while performing multi-level tasks that require grip/manipulation of the hand, elbow/shoulder reaching, sustained overhead work, and sustained positioning with a particular emphasis on assessing the limitations in functional performance attributable to shoulder/neck disorders.

Test Equipment

- The JobSim System (JTech Medical, Salt Lake City, USA) can be used for all FITHaNSA tests.
- The test can also be reproduced with self-made materials using instructions in Appendix 1.

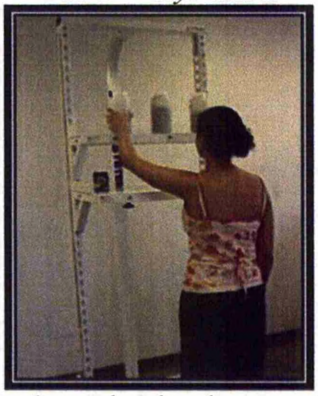
Set-Up with JTech Equipment

Test 1 – "Waist-up"



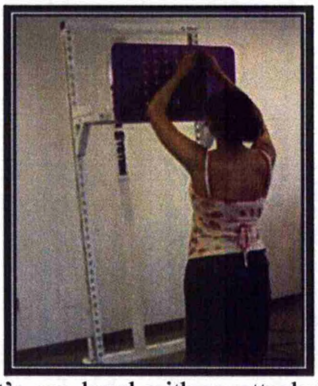
One shelf is placed at the subject's waist level and a second shelf is placed 25 cm above it. The three 1-kg containers are placed 10 cm apart, in line with the screws on the upper shelf, on the lower shelf.

Test 2 – "Eye-down"



One shelf is placed at the subject's eye level and a second shelf is placed 25 cm below it. The three 1-kg containers are placed 10 cm apart, in line with the screws on the upper shelf, on the lower shelf.

Test 3 – "Overhead Work"



A shelf is placed at the subject's eye level with an attachable plate, perpendicular to the shelf, projecting out toward the subject.

One bolt is placed in the top notch of the attachable plate and a second bolt is placed in the third notch down the same column so that there is an empty notch between them.

The bolts (3/8-16x2/4) are arranged so that the standoff and nuts are on alternating sides (e.g., Bolt 1: standoff on left, nut on right; Bolt 2: standoff on right, nut on left).

Test Protocol

TEST 1 – "WAIST-UP": Using the affected arm, the patient lifts three 1-kg containers, one at a time, between a shelf at waist level and a shelf 25 cm higher at a speed of 60 beats per minute, controlled by a metronome (beat 1 - grab, beat 2 – lift and place). Controls are tested using the dominant hand. The subjects and controls perform the task until 5 minutes have elapsed or they feel unable to continue (see test-stopping criteria below).

- *Order and placement of the containers:* Subjects start with the container right in front of them (e.g., the container closest to the hand to be tested) and lift the distant one last. The first container is lifted to the higher shelf, then the second and third containers. When all the containers are on the higher shelf, the subject returns to the beginning and moves the containers down.
- *Standing position:* The patient stands with their feet apart, flat on the ground. When their elbow is tucked at their side, the tip of their finger should touch the lower shelf.

TEST 2 – "EYE-DOWN": Using the affected arm, the patient lifts three 1-kg containers, one at a time, between a shelf at eye level and a shelf 25 cm lower at a speed of 60 beats per minute, controlled by a metronome (beat 1 - grab, beat 2 – lift and place). Controls are tested using the dominant hand. The subjects and controls perform the task until 5 minutes have elapsed or they feel unable to continue (see test-stopping criteria below).

- *Order and placement of the containers:* Subjects start with the container right in front of them (e.g., the container closest to the hand to be tested) and lift the distant one last. The first container is lifted to the higher shelf, then the second and third containers. When all the containers are on the higher shelf, the subject returns to the beginning and moves the containers down.
- *Standing position:* The patient stands with their feet apart, flat on the ground. When their elbow is tucked at their side, the tip of their finger should touch the lower shelf.

Tests 1 and 2 instructions for subjects:
"We would like you to move all 3 containers from this shelf up/back down following the beat of the metronome (60 beats per minute). If you are off cadence, feel pain, or just simply can't continue, let us know and we will stop the timer. If you have reached 5 minutes, the subtest is over and you can rest before the next test."

TEST 3 – "OVERHEAD WORK": Using both arms, the subject repeatedly screws and unscrews bolts (the nut is held, while the standoff is turned) in the top 3 holes in the plate, simulating sustained overhead work.

- Pattern: The bolt in notch 1 (top) moves down to notch 2. The bolt in notch 3 (bottom) moves up to notch 1. The bolt in notch 2 moves down to notch 3. This pattern is repeated until 5 minutes have elapsed or the subjects feel unable to continue (see test-stopping criteria below).
- Standing position: The patient stands with their feet apart, flat on the ground. When their hands are held up, the elbows should be bent (start position).

Test 3 instructions for subjects:

"Screw and unscrew the bolts by staying in the top 3 holes. We want you to hold the nut and turn the standoff. Do NOT twirl the screw. If you drop a bolt, keep your arms up in the air and a tester will give you another one so that you don't bring your arms down." (the tester always has one or two extra bolts ready to go).

Test Stopping Criteria

Each task can be continued for up to 5 minutes, but is terminated based on the following stopping rules:

- The subject stops or states it is too painful to continue.
- The subject is severely off pacing to the extent that they are unable to complete one repetition of the movement within 2 beats of the metronome.
- The subject substitutes using trunk/whole body movement and cannot correct with feedback for 5 successive repetitions of the task.
- The examiner believes the subject is at risk of injury or adverse complication if tests were to continue.

There is an approximately 30-sec rest in between tests as the shelves are adjusted and the patient resumes start position.

Scoring: The times are measured using a stopwatch.

- Test 1 (Waist-Up)/3 00 sec X 100%
- Test 2 (Eye-Down)/ 300 sec X 100%
- Test 3 (Overhead Work)/300 sec X 100%
- Total Score = Mean of Test 1, Test 2 and Test 3

Comparative Data

Population	Sex	n	Test 1 Score in sec (SD), %	Test 2 Score in sec (SD), %	Test 3 Score in sec (SD), %	Total Score in sec (SD), %
Controls						
Development study	M, F	5	300.00 100%	286.50 95.50%	300.00 100%	295.50 98.50%
Validation study	M	8	300.00 (.00) 100%	276.50 (35.97) 92.16%	300.00 (.00) 100%	292.16 (11.98) 97.38%
Validation study	F	11	300.00 (.00) 100%	299.09 (3.02) 99.69%	300.00 (.00) 100%	299.69 (1.00) 99.89%
Patients						
Development study	M, F	5	178.80 59.60%	116.60 38.87%	150.70 50.23%	148.70 49.57%
Validation study	M	8	300.00 (.00) 100%	246.25 (67.30) 82.08%	278.75 (60.10) 92.91%	275.00 (24.78) 91.66%
Validation study	F	9	300.00 (.00) 100%	246.00 (83.90) 82.00%	271.22 (44.96) 90.40%	272.40 (42.60) 90.80%

Legend: F = female, M = male

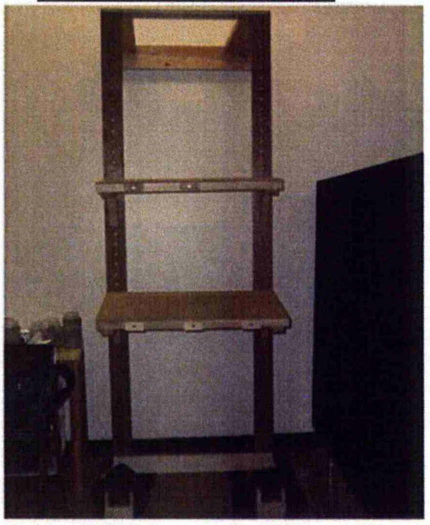
Published Studies

MacDermid, JC, Ghobrial M, Quirion KB, St-Amour M, Tsui T, Humphreys D, McCluskie J, Shewayhat E, Galea V. Validation of a new test that assesses functional performance of the upper extremity and neck (FIT-HaNSA) in patients with shoulder pathology. *BMC Musculoskeletal Disorders* 2007 May 1 7;8(1) :42

Acknowledgements

Investigation of the impact of reach and grasp activities on aspect of EMG and kinematics were formed in the Human Movement Laboratory at McMaster University (Principal investigator – V Galea). The original pilot testing and test development was conducted with D Humphreys, J McCluskie and E Shewayhat. Further development and validation of the test in mild shoulder pathology was performed by M Ghobrial, KB Quirion, M St-Amour, T Tsui. The wooden shelving unit was built by James Bromley.

Wooden Shelving Unit



An adjustable shelving unit was constructed using self-made material. The unit consisted of two cedar uprights with dimensions 3.5 cm X 8.5 cm X 236.5 cm. Holes (2.5 cm diameter) were drilled into the uprights with a 5 cm center to center distance. Two shelves were constructed (78 cm X 45 cm) and were adjustable via two posts made out of 2.5 cm thick dowels. One shelf was constructed with additional objects allowing a dexterity task to be performed with arms raised above the head. The task consisted of fitting turn screws into 6 fittings. The present prototype is not free-standing. The two uprights were fixed into the wall via cedar boards and rested on cedar board frame that was weighted down with sandbags. We are presently adapting this prototype to a free-standing unit.

11.6 Appendix VI: The raw non-electromyography data collected from the study participants

11.6.1 Appendix VI: Table 1: Raw data of normal dominant and non-dominant shoulders of female and male controls.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Female controls (13)				Male controls (21)			
	Dominant		Non-dominant		Dominant		Non-dominant	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric MVC (N)								
Flexors	72.0	10.9	68.0	12.6	107.0	18.8	101.0	17.3
Abductors	66.0	9.2	65.0	12.0	95.0	16.2	94.0	13.1
External Rotators	80.0	17.8	79.0	15.3	108.0	26.5	113.0	29.4
Internal Rotators	132.0	36.9	126.0	33.7	187.0	58.3	165.0	51.5
ROM (°)								
Flexion	180.0		180.0		178.0	4.0	178.0	4.0
Extension	53.0	5.0	55.0	5.0	50.0	6.0	51.0	5.0
Abduction	180.0		180.0		179.0	4.0	178.0	5.0
Horiz. Adduction	45.0	4.0	45.0	4.0	42.0	3.0	42.0	3.0
External Rotation	85.0	5.0	88.0	4.0	74.0	9.0	76.0	10.0
Internal Rotation	10.0		10.0		10.0	1.0	10.0	1.0
Postural measurement								
NSPI (%)	164.0	6.7	160.0	3.5	161.0	13.0	162.0	14.0
SI (%)	72.0	6.9	72.0	6.7	73.7	6.2	73.3	6.2
LSSTP1 (cm)	9.0	0.9	9.0	0.9	9.6	1.2	9.7	1.2
LSSTP2 (cm)	10.0	0.8	10.0	0.9	10.4	1.4	10.4	1.3
LSSTP3 (cm)	12.0	0.5	11.0	0.8	11.9	1.0	11.9	1.0
TKI (%)	10.0	1.4	11.0	1.5	11.4	1.1	13.5	4.1
FHP (°)	56.0	8.4	55.0	5.8	51.9	5.8	55.0	6.6
FSP (°)	54.0	7.0	57.0	3.4	63.5	8.8	56.0	10.6
FIT-HaNSA								
WUT (%)	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
EDT (%)	94.0	8.5	89.0	17.4	96.0	7.6	100.0	0.0
OHT (%)	97.0	5.5	99.0	2.4	99.0	2.9	100.0	0.0
Average	97.0	4.3	95.0	9.1	98.0	3.4	100.0	0.0
Questionnaires								
CMS	88.8	1.8	89.6	2.1	94.8	4.3	96.4	3.2
OSS	48.0	0.0			46.4	2.6		
DASH	0.5	1.2			1.9	3.5		
DASH Option 1	0.0	0.0			0.6	1.8		
DASH Option 2	0.0	0.0			1.2	5.5		
ULFI	0.0	0.0			2.9	7.1		
MPQ	0.0	0.0			0.7	1.5		
HADS	1.2	2.1			0.3	0.7		
HADS (A.C,)	0.8	1.4			0.3	0.7		
HADS (D.C.)	0.4	1.0			0.0	0.0		
GHSF12	16.4	2.1			17.4	3.4		
GHSF12 (P.C.)	8.3	2.1			9.0	2.1		
GHSF12 (M.C.)	7.2	1.4			8.4	1.7		

11.6.2 Appendix VI: Table 2: Raw data of normal shoulders of male Caucasian and male non-Caucasian controls.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Male Caucasian controls (8)				Male non- Caucasian controls (13)			
	Dominant		Non-dominant		Dominant		Non-dominant	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric MVC (N)								
Flexors	91.6	28.5	95.6	31.3	94.7	15.2	99.0	20.3
Abductors	85.1	28.3	97.4	36.6	90.5	12.4	100.9	19.2
External Rotators	82.9	23.5	163.0	66.5	85.4	14.8	168.4	44.7
Internal Rotators	78.7	22.3	145.5	57.1	86.3	12.8	149.4	37.4
ROM (°)								
Flexion	179.0	3.1	44.3	4.1	178.6	3.6	41.8	2.5
Extension	179.0	3.1	44.0	3.8	178.6	3.6	42.1	3.2
Abduction	51.8	4.4	81.5	8.1	51.1	6.8	74.3	9.4
Horiz. Adduction	52.5	4.4	85.0	6.9	52.5	6.4	74.3	10.2
External Rotation	179.5	2.2	9.9	0.4	178.6	3.6	9.4	0.9
Internal Rotation	179.5	2.2	9.9	0.4	177.9	5.8	9.9	0.5
Postural measurement								
NSPI (%)	162.7	12.0	11.8	0.9	161.2	9.7	11.8	0.9
SI (%)	160.2	11.4	11.7	1.1	163.1	11.0	11.7	0.7
LSSTP1 (cm)	100.7	35.0	11.1	2.4	73.3	5.5	11.4	1.2
LSSTP2 (cm)	73.5	6.9	54.6	7.8	72.2	5.4	52.5	5.8
LSSTP3 (cm)	9.2	1.1	55.2	8.2	9.6	1.0	63.6	9.1
TKI (%)	9.1	1.1			9.8	1.0		
FHP (°)	10.5	1.0			10.1	1.4		
FSP (°)	10.4	1.0			10.2	1.4		
FIT-HaNSA								
WUT (%)	100.0	0.0	97.9	4.8	100.0	0.0		
EDT (%)	100.0	0.0	99.3	2.0	98.7	3.4		
OHT (%)	95.6	7.6	97.8	3.8	94.9	8.5		
Average	92.6	14.8	96.4	7.7	97.8	3.8		
Questionnaires								
CMS	92.0	5.2	92.2	4.9	93.2	3.7	93.0	4.4
OSS	47.5	1.5			46.4	2.8		
DASH	0.9	2.1			1.9	3.8		
DASH Option 1	0.0	0.0			0.9	2.2		
DASH Option 2	1.3	5.6			0.0	0.0		

ULFI	0.4	1.8	3.7	8.4
MPQ	0.3	1.1	0.7	1.3
HADS	1.0	1.8	0.3	0.7
HADS (A.C,)	0.7	1.2	0.3	0.7
HADS (D.C.)	0.3	0.8	0.0	0.0
GHSF12	16.5	2.4	17.7	3.7
GHSF12 (P.C.)	8.3	1.9	9.4	2.4
GHSF12 (M.C.)	7.6	1.6	8.4	1.8

11.6.3 Appendix VI: Table 3: Raw data for shoulders of female patients with unilateral (UIMP) or bi-lateral (BIMP) impingement syndrome.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Female UIMP Patients (11)				Female BIMP Patients (5)			
	Affected		Unaffected		More Affected		Less Affected	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric MVC (N)								
Flexors	42.6	14.8	64.8	8.7	27.4	12.5	37.1	18.4
Abductors	34.5	12.5	59.0	10.3	24.6	5.7	31.3	19.0
External Rotators	54.3	16.7	73.1	17.5	46.8	11.3	52.5	8.3
Internal Rotators	74.4	33.3	109.8	41.6	48.7	27.9	65.0	23.8
ROM (°)								
Flexion	122.7	27.4	170.0	6.3	120.0	18.7	142.0	43.2
Extension	32.7	7.9	45.5	4.7	34.0	8.9	42.0	8.4
Abduction	106.8	32.7	165.5	13.7	103.0	11.0	128.0	40.9
Horiz. Adduction	40.0	8.9	46.4	5.0	37.0	11.5	39.0	10.8
External Rotation	52.7	19.0	68.6	11.0	48.0	11.0	60.0	17.0
Internal Rotation	4.7	2.4	8.7	1.8	5.2	1.1	8.0	2.4
Postural measurement								
NSPI (%)	159.6	10.1	161.2	8.5	161.4	5.3	164.0	9.0
SI (%)	70.9	5.5	69.3	7.4	70.9	9.2	69.2	8.0
LSSTP1 (cm)	9.0	2.2	9.5	2.2	8.5	1.8	8.7	2.0
LSSTP2 (cm)	9.8	2.1	10.5	1.9	8.9	2.1	9.7	1.7
LSSTP3 (cm)	10.5	2.3	11.7	2.1	9.5	2.3	10.2	1.5
TKI (%)	10.2	2.9			10.7	3.3		
FHP *(°)*	51.17	10.7			45.8	6.8		
FSP *(°)*	43.90	7.9			48.6	14.1		
FIT-HaNSA								
WUT (%)	62.5	25.3	80.3	22.9	44.9	15.1	64.0	31.2
EDT (%)	36.0	18.5	45.6	17.6	21.7	5.5	16.0	.
OHT (%)	51.1	17.7	63.9	17.5	27.6	11.0	42.3	11.6
Average	49.9	18.9	63.3	17.5	31.8	8.9	42.1	15.1
CMS								
Pain	45.5	13.3	85.0	6.9	47.1	10.4	59.5	16.6
Activity	6.5	3.4	14.4	1.6	5.8	2.6	9.2	3.3
Sleep	10.0	3.2	17.2	1.5	8.6	3.2	13.0	3.5
ROM	0.5	0.5	1.9	0.3	0.8	0.8	1.0	1.0

Power	20.7	6.0	38.4	2.9	25.2	7.2	29.6	8.3
Total	7.7	2.8	13.2	2.4	5.5	1.3	7.1	4.2
Other Questionnaires								
OSS	26.4	7.7			17.8	6.1		
DASH	50.1	13.8			62.0	12.6		
DASH Option 1	26.1	28.9			15.0	22.4		
DASH Option 2	9.7	23.6			40.0	41.8		
ULFI	38.9	10.0			64.0	18.3		
MPQ	20.5	12.6			27.4	11.4		
HADS	12.6	8.2			20.0	7.3		
HADS (A.C,)	7.8	4.4			10.8	4.0		
HADS (D.C.)	4.8	4.3			9.2	3.7		
GHSF12	30.7	6.4			40.0	5.3		
GHSF12 (P.C.)	15.5	3.7			19.2	3.4		
GHSF12 (M.C.)	15.3	3.0			21.2	2.6		

11.6.4 Appendix VI: Table 4: Raw data for affected and unaffected shoulders of improved female patients with unilateral impingement (UIMP) syndrome.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Female improved UIMP patients (4)			
	Affected		Unaffected	
	Mean	SD	Mean	SD
Isometric MVC (N)				
Flexors	52.1	6.5	59.3	7
Abductors	49.1	5	59.9	11.7
External Rotators	73	26.3	69.6	10
Internal Rotators	89	20	102.5	50.1
ROM (°)				
Flexion	172.5	9.6	177.5	5
Extension	55	4.1	57.5	2.9
Abduction	177.5	5	180	0
Horiz. Adduction	42.5	2.9	43.8	2.5
External Rotation	66.3	4.8	70	8.2
Internal Rotation	9.5	1	9.5	1
Postural measurement				
NSPI (%)	164.7	15.7	163.3	17.4
SI (%)	74.3	3.7	72.1	1.2
LSSTP1 (cm)	9	2.5	8.9	2.4
LSSTP2 (cm)	9.5	2.3	10.1	2.6
LSSTP3 (cm)	11	2.5	11.1	2.3
TKI (%)	12.8	0.7		
FHP (°)	43.8	5.4		
FSP (°)	58.8	10.7		
FIT-HaNSA				
WUT (%)	91.3	17.5		
EDT (%)	73.3	19		
OHT (%)	83.3	19.6		
Average	82.6	13.5		
CMS				
Pain	13	2.8	13.8	2.5
Activity	17.5	2.4	19.3	1
ROM	39	2	38.5	3
Power	11	1.2	13.2	2.6
Total	80.5	9.1	84.7	8.7
Other Questionnaires				
OSS	41	5.3		
DASH	15.7	11.3		
DASH Option 1	31.3	23.9		
DASH Option 2	18.8	23.9		
ULFI	28	32.7		
MPQ	15	17.3		
HADS	11	15.4		
HADS (A.C,)	5.8	6.2		
HADS (D.C.)	5.3	9.2		
GHSF12	24.5	6.2		
GHSF12 (P.C.)	12	3.5		
GHSF12 (M.C.)	12.5	2.9		

11.6.5 Appendix VI: Table 5: Raw data for affected and unaffected shoulders of male patients with unilateral (UIMP) or bi-lateral (BIMP) impingement syndrome.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Male UIMP Patients (6)				Male BIMP Patients (7)			
	Affected		Unaffected		More Affected		Less Affected	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric MVC (N)								
Flexors	91.9	30.1	115.6	15.8	58.5	34.6	74.7	37.4
Abductors	66.8	29.9	99.3	21.3	46.3	36.4	68.1	35.8
External Rotators	102.2	19.9	123.2	36.9	69.2	34.6	87.3	53.1
Internal Rotators	143.0	56.7	208.4	48.5	103.4	73.8	142.5	86.2
ROM (°)								
Flexion	140.0	42.9	176.7	5.2	127.1	35.5	147.1	43.9
Extension	40.0	9.5	48.3	2.6	35.7	7.3	42.1	9.1
Abduction	128.3	50.0	176.7	5.2	114.3	46.1	145.0	44.3
Horiz. Adduction	37.5	6.1	42.5	2.7	38.6	9.0	41.4	9.0
External Rotation	52.5	17.0	68.3	9.3	46.4	16.3	59.3	15.4
Internal Rotation	5.3	2.7	8.7	1.0	4.3	2.1	6.3	2.4
Postural measurement								
NSPI (%)	152.2	6.3	150.6	9.3	160.7	6.3	160.8	10.5
SI (%)	73.0	8.5	74.0	7.1	77.0	8.8	78.2	11.0
LSSTP1 (cm)	9.8	1.2	10.2	1.3	9.7	1.5	9.6	1.7
LSSTP2 (cm)	10.5	1.1	11.5	1.3	11.4	2.4	11.6	2.3
LSSTP3 (cm)	11.3	1.1	12.5	1.1	11.8	0.7	12.2	0.7
TKI (%)	11.2	2.4			10.7	2.0		
FHP (°)	43.3	11.3			45.0	12.0		
FSP (°)	50.4	9.8			47.8	8.8		
FIT-HaNSA								
WUT (%)	72.0	31.4	94.8	10.5	63.4	41.6	76.3	33.9
EDT (%)	58.1	36.3	57.5	33.0	44.9	26.7	52.0	39.2
OHT (%)	36.1	15.8	66.4	5.6	60.5	26.3	64.2	26.2
Average	55.4	20.8	72.9	16.4	50.4	32.2	64.1	31.2
CMS								
Pain	6.7	2.9	14.3	0.8	5.0	4.9	7.4	4.7
Activity	11.0	2.6	19.3	1.2	8.4	6.2	12.0	6.2
ROM	24.0	7.5	38.7	1.6	19.7	11.5	28.0	11.8
Power	14.9	6.7	21.3	3.4	13.7	8.3	14.1	8.2
Total	56.6	18.3	93.7	5.4	45.6	23.9	59.8	28.6
Other Questionnaires								
OSS	28.2	6.5			21.8	9.0		
DASH	44.4	17.2			62.2	10.9		
DASH Option 1	33.3	30.3			36.6	37.7		
DASH Option 2	35.4	32.0			28.6	40.2		
ULFI	44.7	20.8			59.4	10.9		
MPQ	26.7	23.5			31.0	20.2		
HADS	10.8	9.1			20.6	9.9		
HADS (A.C,)	7.2	5.8			12.1	4.5		
HADS (D.C.)	3.7	3.3			8.4	5.8		
GHSF12	29.0	10.8			40.1	6.9		
GHSF12 (P.C.)	14.0	5.3			19.6	2.9		
GHSF12 (M.C.)	15.0	5.7			21.3	3.5		

11.6.6 Appendix VI: Table 6: Raw data for shoulders of male unilateral impingement (UIMP) patients who have associated shoulder pathology.

The presented values are the average isometric maximum voluntary contraction (MVC, N), range of motion (ROM, °), postural measurements, functional impingement test-hand, and neck/shoulder/arm (FIT-HaNSA, %) and self-reporting questionnaires.

Tests	Male UIMP Patients with associated shoulder pathology (6)			
	Affected		Unaffected	
	Mean	SD	Mean	SD
Isometric MVC (N)				
Flexors	75.3	24.7	107.6	27.1
Abductors	70.0	26.8	93.7	19.5
External Rotators	82.7	31.8	107.1	12.9
Internal Rotators	116.8	75.3	176.2	58.7
ROM (°)				
Flexion	140.0	52.5	175.0	8.4
Extension	40.0	10.5	47.5	4.2
Abduction	130.8	49.0	176.7	8.2
Horiz. Adduction	33.3	10.8	42.5	4.2
External Rotation	53.3	18.6	65.8	12.0
Internal Rotation	5.3	2.4	9.0	1.1
Postural measurement				
NSPI (%)	153.2	13.7	148.7	3.6
SI (%)	73.6	3.2	74.7	5.3
LSSTP1 (cm)	9.5	2.1	9.2	2.2
LSSTP2 (cm)	10.1	2.0	10.6	2.2
LSSTP3 (cm)	10.9	1.8	11.5	2.1
TKI (%)	10.4	2.8		
FHP (°)	52.2	11.5		
FSP (°)	51.6	11.4		
FIT-HaNSA				
WUT (%)	70.9	27.2		
EDT (%)	55.1	28.1		
OHT (%)	70.6	27.1		
Average	65.5	23.3		
CMS				
Pain	6.3	5.0	14.0	1.7
Activity	9.5	5.3	18.8	1.6
ROM	22.0	10.6	38.3	4.1
Power	14.1	9.0	20.6	3.6
Total	54.3	26.4	92.2	8.6
Other Questionnaires				
OSS	22.3	8.9		
DASH	48.1	23.4		
DASH Option 1	59.4	33.5		
DASH Option 2	33.3	41.0		
ULFI	54.0	24.2		
MPQ	26.8	11.5		
HADS	15.5	11.9		
HADS (A.C,)	7.5	6.0		
HADS (D.C.)	6.0	7.8		
GHSF12	31.0	9.9		
GHSF12 (P.C.)	16.0	3.9		
GHSF12 (M.C.)	17.8	3.5		

11.7 Appendix VII: Data related to the discussion chapter

11.7.1 Appendix VII: Table 1: The percentage and deficit (%) of the mean muscle strength between female (FC) and male (MC) controls.

Abd = abduction, Flex = flexion, ER = external rotation and IR = internal rotation.

Muscle Strength	Female controls	Male controls	Strength ratio FC:MC %	Deficit %
Flexors	67.8	103.7	68.8	31.2
Abductors	64.1	94.5	62.3	37.7
External rotators	77.8	110.4	76.9	23.1
Internal rotators	124.4	175.8	69.7	30.3
Abd/Flex	0.95	0.91		
ER/IR	0.63	0.63		

11.7.2 Appendix VII: Table 2: The percentage and deficit (%) of the mean muscle strength of affected shoulders between female and male study groups.

Abd = abduction, Flex = flexion, ER = external rotation and IR = internal rotation. P = patients and C = controls.

Muscle Strength	Female patients Affected shoulder	Female controls	Strength ratio P:C %	Deficit %	Male patients Affected shoulder	Male controls	Strength ratio P:C %	Deficit %
Flexors	37.7	67.8	55.6	44.4	71.3	103.7	68.8	31.2
Abductors	31.4	64.1	49.0	51.0	58.9	94.5	62.3	37.7
External rotators	52.1	77.8	67.0	33.0	84.9	110.4	76.9	23.1
Internal rotators	66.0	124.4	53.1	46.9	122.6	175.8	69.7	30.3
Abd/Flex	0.83	0.95			0.83	0.91		
ER/IR	0.79	0.63			0.69	0.63		

11.7.3 Appendix VII: Table 3: The percentage and deficit (%) of the mean muscle strength of unaffected shoulders between female and male study groups.

Abd = abduction, Flex = flexion, ER = external rotation and IR = internal rotation. P = patients and C = controls.

Muscle Strength	Female patients Unaffected shoulder	Female controls	Strength ratio P:C %	Deficit %	Male patients Unaffected shoulder	Male controls	Strength ratio P:C %	Deficit %
Flexors	64.8	67.8	95.6	4.4	109	103.7	105.1	-5.1
Abductors	59.0	64.1	92.0	8.0	95.1	94.5	100.6	-0.6
External rotators	73.1	77.8	94.0	6.0	112.7	110.4	102.1	-2.1
Internal rotators	109.8	124.4	88.3	11.7	194	175.8	110.4	-10.4
Abd/Flex	0.91	0.95			0.87	0.91		
ER/IR	0.67	0.63			0.58	0.63		

11.7.4 Appendix VII: Table 4: Normal values of range of motion from asymptomatic individuals as provided in the literature.

Author	Flexion	Extension	Abduction	Medial Rot.	Lateral Rot.
Steindler (1955)[548]	180	30-40	150		
US Army/Air force (1986)[549]	180	60	180	70	90
Boone and Azen (1979)[550]	165	57.3	182.7	67.1	99.6
Hislop and Montgomery (1995)[551]	180	45	180	80	60
Murray et al. (1985)[137]	170	57	178	49	94
Gerhardt and Rippstein (1990)[552]	170	50	170	80	90

11.7.5 Appendix VII: Table 5: The percentage and deficit % of the mean range of motion (ROM) of affected shoulders between female and male study groups.

P = patients and C = controls.

ROM	Female patients	Female controls	Strength ratio P:C %	Deficit %	Male patients	Male controls	Strength ratio P:C %	Deficit %
	Affected shoulder				Affected shoulder			
Flexion	126.7	180	70.4	29.6	138.5	178.1	77.8	22.2
Extension	35.2	53.8	65.4	34.6	39.4	50.8	77.6	22.4
Abduction	111	180	61.7	38.3	129.6	178.3	72.7	27.3
Horiz. adduction	39	45.4	85.9	14.1	37.9	41.9	90.5	9.5
External rotation	53.3	86.5	61.6	38.4	52.9	75.2	70.3	29.7
Internal rotation	5.6	10	56.0	44.0	5.3	9.7	54.6	45.4

11.7.6 Appendix VII: Table 6: The percentage and deficit % of the mean range of motion of unaffected shoulders between female and male study groups.

P = patients and C = controls.

ROM	Female patients	Female controls	Strength ratio P:C %	Deficit %	Male patients	Male controls	Strength ratio P:C %	Deficit %
	Unaffected shoulder				Unaffected shoulder			
Flexion	170	180	94.4	5.6	175.8	178.1	98.7	1.3
Extension	45.5	53.8	84.6	15.4	47.9	50.8	94.3	5.7
Abduction	165.5	180	91.9	8.1	176.7	178.3	99.1	0.9
Horiz. Adduction	46.4	45.4	102.2	-2.2	42.5	41.9	101.4	-1.4
External rotation	68.6	86.5	79.3	20.7	67.1	75.2	89.2	10.8
Internal rotation	8.7	10	87.0	13.0	8.8	9.7	90.7	9.3

11.7.7 Appendix VII: Table 7: Normal mean values of thoracic kyphosis index (TKI) from asymptomatic individuals as provided in the literature.

Author	Age group or mean	Women			Men		
		Mean	SD	N	Mean	SD	N
Dunleavy et al. (2010)[430]	21-30	10.2		20	10.2		2
Current study (Controls)	28-68 45.8 (10)	10.1	1.3	12	10.5	2.4	18
Chow and Harrison. (1987)[458]	50-60 55.2 (2.5)	10.7	3.1	27			
Milne and Lauder (1976)[510]	62-64	10.7	2.3	42	10.5	2.5	46
	65-69	11.7	2.8	93	11.1	3	75
	70-74	12.7	2.9	55	11.7	2.9	38
	75-79	13.9	3.9	45	12.2	3.6	34
	80-90	16	5	30	12.2	3.5	20

11.7.8 Appendix VII: Table 8: Normal mean values of forward head posture (FHP) and forward shoulder posture (FSP) from female and male asymptomatic volunteers.

Author	Posture	Age group or mean	Women				Men			
			Mean	SD	Range	N	Mean	SD	Range	N
Raine and Twomey (1997)[154]	FHP	All	50.1	5.5	35-63	87	47.4	7.3	28-62	78
		17-29	51.9	4.4	43-63	35	52.2	5.2	40-62	21
		30-54	50.8	4.8	43-61	28	47.6	5.9	35-58	27
		55 & above	46.8	6.2	35-59	24	44	7.9	28-62	30
	FSP	All	54.3	11.5	32-92	87	53	13.5	25-83	78
		17-29	50.3	11.2	33-93	35	46.7	12.9	28-82	21
		30-54	55.2	12.3	32-78	28	56.1	12.9	30-80	27
		55 & above	59.3	9.2	42-83	24	54.6	13.5	25-83	30
Current Study (controls)	FHP	28-68	55.5	8.3		12	47	11.4		18
	FSP	45.8 (10)	53.6	7		12	49.7	9.2		18

11.7.9 Appendix VII: Table 9: Functional impairment test score from asymptomatic volunteers. WUT, EDT and OHT indicate the waist-up, eye-down and overhead tasks respectively.

Gender	Task	Roy et al. (2009)[138]			MacDermid et al. (2007)[58]			Current study		
		Age mean	N	%	Age mean	N	%	Age mean	N	%
Women	WUT	48.8 (5.1)	13	100	32 (12)	11	100	42.9 (9.3)	18	100
	EDT			91.3			99.6			92.1
	OHT			97.7			100			97.7
Men	WUT	48.5 (5.3)	8	100	32(12)	8	100	47.6 (10.3)	22	100
	EDT			94.2			92.2			96.8
	OHT			94.3			100			99.2